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Environmental Factors Affecting Long-Term Stabilization of Radon Suppression Covers for Uranium Mill Tailings

Prepared by J. K. Young, L. W. Long, J. W. Reis

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Pacific Northwest Labaoratory is investigating the use of a rock armoring blanket (riprap) to mitigate wind and water erosion of an earthen radon suppression cover applied to uranium mill tailings. To help determine design stresses for the tailings piles, environmental parameters are characterized for the five active uranium-producing regions on a site-specific basis. Only conventional uranium mills that are currently operating or that are scheduled to open in the mid 1980s are considered.

Available data indicate that flooding has the most potential for disrupting a tailings pile. The arid regions of the Wyoming Basins and the Colorado Plateau are subject to brief storms of high intensity. The Texas Gulf Coast has the highest potential for extreme precipitation from hurricane-related storms. Wind data indicate average wind speeds from 3 to 6 m/sec for the sites, but extremes of 40 m/sec can be expected. Tornado risks range from low to moderate. The Colorado Plateau has the highest seismic potential, with maximum acceleration caused by earthquakes ranging from 0.2 to 0.4 g. Any direct effect from volcanic eruption is negligible, as all mills are located 90 km or more from an igneous or hydrothermal system.

SUMMARY

Pacific Northwest Laboratory (PNL) is studying the mitigation of erosion through the use of rock aggregate riprap applied to a soil-layer radon suppression cover, used to decrease radon-222 exhalation from uranium mill tailings. An early task in this study, sponsored by the Nuclear Regulatory Commission, is to evaluate the environmental factors that affect the integrity of mill tailings covers, with and without stabilization. Related data on environmental conditions for active and proposed United States uranium mills are presented in this report. This study includes only conventional uranium mills. Solution mining, phosphoric acid byproduct operations, and heap leaching operations are not included because they generate a relatively small amount of tailings.

For the sites studied, information was obtained from Environmental Impact Statements, license applications, and architectural and engineering reports. To aid in evaluating topographic and hydrologic conditions, the mills were sited on topographic maps and orthophotoquads available from the U.S. Geological Survey. Soil Conservation Survey data supplemented the information on soil characteristics available from individual Environmental Impact Statements. Tectonic information is given as well.

Because many environmental characteristics do not change from site to site, regional characteristics are evaluated for the following five areas: the Colorado Plateau, Eastern Washington, the Southern Rocky Mountains, the Texas Gulf Coast, and the Wyoming Basins. Characteristics discussed involve meteorology, climatology, topography, geology, hydrology, and soil conditions. Regional data provide a general overview of environmental conditions, and can be used when site-specific data are not available.

The major scope of the study, however, was to evaluate environmental conditions on a site-specific basis, as such data can be used to determine the range and frequency of important variables that determine erosion potential. More accurate conditions for field studies can then be determined. Available site-specific data concerning eolian erosion, flooding, and seismic and geothermal disruption are presented in tabular form in this report. Based on data in these tables, disruption parameters are summarized in the following table:

TABLE S.1. Disruption Parameters Summarized by Region

	Eastern Washington	Wyoming Basins	Colorado Plateau	Texas Gulf Coast	Southern Rockies
Number of Mills	2	11	13	2	3
Runoff Potential	Low to High	Moderately Low to High	Medium to High	Low to Moderately Low	High
Maximum Probable Precipitation (point value)	NA	48 cm in 6 h	50 cm in 6 h	NA	33 cm in 1 h
Tornado Potential	Low	Low	Low	Moderate	Low
Wind Erosion Potential	High	Medium	Low to High	Medium	Medium
Maximum Earthquake Acceleration	0.1 g	0.03 to 0.05 g	0.05 to 0.4 g	0.06 g	0.2 g

Available data indicate that flooding has the most potential for disrupting a tailings pile. The arid regions of the Wyoming Basins and Colorado Plateau are subject to brief storms of high intensity (e.g., Big Thompson flood in Colorado). Normally, dry streams and washes are inundated by surface runoff. High water velocities result in narrow stream channels. Tailings ponds for the older mills have often been designed to contain surface runoff from the site to minimize danger of contamination. When the tailings ponds are reclaimed, the surface drainage to the tailings pond will increase the risk of water erosion. Newer mills often divert surface runoff away from the tailings through man-made channels and ditches. The disruptive force of the surface runoff at these sites will be a function of the long-term integrity of the diversion structures. Flood parameters are difficult to determine as data on stream discharge rates are sparse and, frequently, misleading. For the sites where the flood potential has been accurately determined, stream velocities of 5 meters per second (m/sec) have been reported.

The Texas Gulf Coast has the highest potential for extreme precipitation from hurricane-related storms. The humid climate has a beneficial effect on vegetation density but a high likelihood of drought is present within a 1000-year period.

Wind erosion occurs when soil or rock are gradually removed as suspended dust particles. Historical wind data indicate that average wind speeds for the sites range from 3 to 6 m/sec for the uranium mill sites studied, but extremes of 40 m/sec can be expected. Tornado risk is low for all areas except the Texas Gulf Coast, but all mills have a medium to high potential for wind erosion.

Seismic risks can occur at any of the sites studied; however, the extreme northwest portions of the Colorado Plateau have the highest seismic potential. Two mills in the northwestern region of the Colorado Plateau estimated maximum ground acceleration caused by earthquakes to be 0.2 g and 0.4 g, respectively.

Any direct effect from a volcanic or geothermal eruption would be negligible as all of the currently operating mills are located at least 90 km from an igneous or hydrothermal system. As evidenced by the Mt. St. Helens' eruption, indirect effects are possible hundreds of kilometers from the eruption. Primary indirect effects include weather changes, ash deposition, and vegetation death. The latter two effects could reduce the permeability of the ground surface, which in turn could lead to floods and mudflows.

RECOMMENDATIONS

Flooding appears to have the greatest disruptive potential of the phenomena considered in this report. Therefore the effect of a Probable Maximum Flood (PMF) series must be established while ascertainaing the long-term safety of a tailings pond. The PMF series is defined by Regulatory Guide 3.11 as the combined runoff from a 100-year storm event, plus a probable maximum precipitation event, followed by 40% of a probable maximum precipitation event. The adequacy of this regulation for a 1000-year time period should be evaluated.

The effect of a PMF series has not been analyzed for many mills; for several others, the PMF evaluations may not be adequate to determine long-term stability. Many of the older mills considered only current site conditions in their analyses. Site topography may change in response to new reclamation regulations, making existing PMF series studies obsolete. Thus, PMF analysis should be performed with the topography of the reclaimed surface in mind.

If other parameters are found to be as important as flooding, similar analyses determining the maximum event and its effects for existing site conditions and for conditions 1000 years hence will be necessary.

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1.0 INTRODUCTION

Current Nuclear Regulatory Commission (NRC) regulations specify that maximum radon-222 exhalation from uranium mill tailings shall not exceed 2 pci/m^2-sec. Suppression covers being considered to decrease radon release include a soil layer 3 to 5 m thick. Because the parent of radon has a half-life of 80,000 years, mitigating action will have to be taken to protect this soil layer from erosion and disruption by natural phenomena such as wind, rain, floods, and possibly earthquakes. Pacific Northwest Laboratory (PNL) is studying the mitigation of erosion through the use of rock aggregate riprap applied to the radon suppression cover. This study is sponsored by NRC.

To help develop guidelines for the use of riprap covers, this report characterizes environmental conditions at currently operating or planned uranium mills. These environmental conditions will serve as input to later tasks that will model and provide bounds to potential stresses that could affect a tailings area. All data on environmental conditions are obtained from open literature. Results of potential stresses that have been quantified in the literature are included in this report. However, analyses of maximum disruptive events such as Probable Maximum Floods (PMF) are beyond the scope of this study. These analyses will be performed for selected sites in following reports.

Both regional and site-specific data are present in this report. Regional data broadly describe important characteristics such as climate, soils, geology, hydrology, and seismicity and provide background for the site-specific characterization. Regional data can also be used to supplement site-specific environmental data when applicable. For the most part, the regions outlined correspond to natural physiographic provices. Site-specific data are obtained to help determine the bounds of local maximum stresses. Important characteristics include local geology, topography, soils, hydrology and tailings area design.

Information for the sites studied was obtained from Environmental Impact Statements, license applications, and architectural and engineering reports. To aid in evaluating topographic and hydrologic conditions, the mills were sited on topographic maps and orthophotoquads available from the U.S. Geological Survey (U.S.G.S.). Soil Conservation Survey data supplemented the information on soil characteristics available from individual Environmental Impact Statements. Tectonic information was obtained from the U.S.G.S.

Following careful consideration of the environmental parameters presented in this report, three or four actual mill sites will be chosen for a complete analysis of maximum potential stresses. Long-term scenarios will be formulated for the representative sites. For each scenario, a technical and economic evaluation of riprap as a long-term mitigation cover will be performed.

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2.0 SCOPE AND METHODOLOGY

The scope of our investigation is limited to tailings repositories from conventional uranium mills that are currently operating and from new mills scheduled to open in the mid-1980s. Uranium operations not considered in the study include solution mines, phosphoric acid byproduct recovery, and heap leaching. Tailings repositories from abandoned mills are covered by the Uranium Mill Tailings Remedial Action (UMTRA) mandate and do not fall within the scope of this work, although related results may be of great value in the remedial action program.

Because predictions for the distant future contain large degrees of uncertainty, this study only considers disruptive environmental effects that could occur over the next 1000 years. Those factors viewed as having the greatest long-term impact are wind, precipitation, and surface flooding. Flooding appears to have the greatest potential for disrupting a tailings pile. More catastrophic phenomena, such as earthquakes and magmatic events, have a much smaller likelihood of disrupting tailings repositories; however, because these events could occur within 1000 years, they have been considered.

Geologic processes that have much longer frequency horizons, such as extreme climatic fluctuations and associated ice sheets and changes in sea level, are not considered relevant to the study. Random events of small probability, such as meteorite impacts, are not included.

Because of the number and geographic distribution of domestic uranium mills, regional and local variations in site characteristics and environmental factors are considered. Our approach has been to define broad geographic regions that include natural groupings of mill sites. Generally, these regions coincide with resource regions previously established by the National Uranium Resource Evaluation (NURE) Program (U.S. Energy Research Development Administration 1976).

Most of the background information on regional physical and environmental characteristics was obtained from a generic environmental impact statement recently completed on uranium-producing regions (Argonne National Laboratory 1979). Regional data were also obtained from various NURE and National Oceanic and Atmospheric Administration (NOAA) documents, license applications, and architectural and engineering reports. Tectonic information was obtained from the U.S. Geological Survey.

Evaluations of local variations were based on government hydrologic, topographic, and meteoric surveys as well as on data contained in site-specific environmental impact statements. Specifically, each uranium mill complex and tailings dump was spotted on 7-1/2 or 15-min topographic sheets (available from the U.S. Geological Survey) to determine the proximity to surface water and local geomorphic features. When available, historic stream flow rates, meteoric conditions, and geologic stability were assessed to predict the long-term performance of soil radon suppression covers and riprap stabilization layers.

Although we believe that the most relevant literature was reviewed, a study of all documents concerning this subject was impossible. Thus, where tables in the following sections suggest that certain information was not available (NA), further research in that particular area may be indicated.

3.0 POTENTIAL DISRUPTIVE PHENOMENA

Natural phenomena that may disrupt uranium tailings piles over the next 1000 years must be identified to determine which environmental parameters are important to the evaluation of the performance of long-term radon suppression covers. Water and wind have the greatest potential for destruction; however, geologic events resulting from faults and geothermal activity may also disrupt tailings. Because these geologic forces are less ubiquitous, they represent a smaller potential for disruption. Such natural hazards, as well as parameters that may be used to model their impacts, are outlined below. Detailed parameters are presented in later sections on site-specfic disruption.

3.1 WATER EROSION

Water erosion of tailings piles can result from rain sheet erosion or from runoff flooding. Of the two, flooding is a potentially more disruptive single event; however, sheet erosion can be expected to occur more often and may eventually be as damaging. These two erosional forces are not necessarily independent events (i.e., thunderstorms cause sheet erosion but may also result in flash flooding by rapid runoff).

Parameters useful in modeling sheet erosion include mean and maximum annual precipitation and maximum 12-h precipitation. Knowledge of the percent of precipitation occurring as snowfall is useful in modeling.

Flooding could be anticipated by knowing the proximity of tailings piles to surface drainage systems, as well as the slope and runoff characteristics of the surrounding terrain. Specific knowledge of distance to the nearest drainage as well as of mean and maximum flow rates is important. Also, whether tailings impoundments are built across natural drainages or within established flood boundaries should be known. Runoff parameters include slope, vegetation density, and soil permeability.

3.2 WIND EROSION

Surface erosion by wind can result when soil is gradually removed as suspended dust particles. More rapid soil erosion may occur during violent windstorms or tornados. Also, disruption can result from wind-generated wave action and blowing rain or ice.

Wind erosion to uranium tailings piles can be predicted with historic wind data. Tailings pile dimensions and topographic features, as well as orientation to prevailing wind direction, provide a measure of future erosion potential. Physical characteristics of tailings and surrounding soil are useful in determining the susceptibility to removal and transportation by wind. Disruption by tornados is predicted by historic tornado frequency data.

3.3 GEOLOGIC DISRUPTION

Geologic forces that may disrupt uranium tailings piles include earthquakes and extrusive geothermal systems. Earthquakes are far more common than extrusive events and have greater potential for eventually causing tailings containment failure. Although extrusion by geothermal systems is rare, single events can be catastrophic, as witnessed by the recent eruption of Mount St. Helens in southwestern Washington.

Historic earthquake frequency data can be used as parameters to predict future activity. Because earthquakes typically occur along existing faults, another measure of potential disruptive activity is the proximity of tailings piles to existing faults, even if movement has not been recorded. When earthquakes occur along existing faults, the area of rupture is usually less than 50% of the fault length. Past studies have estabished relationships between fault rupture length and earthquake intensity (Bonilla and Buchanan 1970). According to these data, faults would have to be at least 10 km in length to produce earthquakes capable of significantly disrupting a tailings pile. Distance to active faults and fault length data are presented when available in the literature.

If soil or uranium tails contain significant amounts of water, ground shaking can result in a complete loss of strength through liquefaction. Specifically, as ground shaking decreases pore space and increases pore water pressure to a point equal to total stress, sheer strength goes to zero. Parameters useful in predicting liquefaction are porosity, permeability, water content, and tailings pile slope.

The results of extrusive events can be estimated by considering the proximity of tailings dumps to geothermal systems identified by the U.S.G.S. (Nelson and Shepherd 1978). Pertinent parameters would be distance to the tailings site and magnitude of the geothermal system.

3.4 LONG-TERM GEOMORPHIC PROCESSES

Because the environmental factors that influence surface erosion change with time, a definition of relevant cause-and-effect processes is necessary. Within a time span of 1000 years, no major climatic changes or crustal movements are expected that will greatly alter erosional rates. Local anomalies, under current conditions, pose the greatest threat.

Variables that determine the shape and stability of physical landforms are time dependent. In the short term, such things as vegetation, hydrology, climate, geology, drainage network, and hillslope morphology interact to determine erosional patterns. For longer time spans (greater than a few thousand years), the independent variables are reduced to climate, geology, and time (Schumm and Lichty 1965). However, long time spans are subject to more disruptive events, such as catastrophic glacial flooding, major climatic changes, and changes in relief by crustal movements.

Although major climatic changes are complex, certain cyclic patterns are recognized. Major glaciations seem to occur every 150 million years and last up to 50 million years; however, the evidence is incomplete. The pattern of glacial and interglacial stages that occur on a time scale of 25,000 to 100,000 years is better understood and is highly correlated with known perturbations in astronomical periodicities (John 1979). On a shorter time scale, and more relevant to the study of tailings stabilization, is the cycle of "little ice ages" that occur approximately every 2500 years and are closely tied to pulsations in solar radiation (Gribbin 1978).

In addition to climatic changes, changes in relief resulting from crustal deformation affect surface erosion. Geologic processes typically associated with crustal deformation are tectonic stress and isostatic adjustment to accommodate loading or unloading of sediments, ice, or water. In any event, 1000 years is not sufficient time for changes in crustal relief to significantly alter erosional patterns. Assuming no major changes in relief or climatic conditions, the physical processes affecting uranium-producing areas would be "steady-state" denudation, entrenchment, and aggradation.

Rates of landform erosion over long periods of time (denudation) have been estimated for river basins under different climatic conditions and are presented in Table 3.1. Denudation rates caused by the precipitation required to produce a known amount of runoff (effective precipitation) have also been estimated and are presented in Table 3.2.

TABLE 3.1. Denudation Rates for River Basins in Various Climates(a)

Region	Denudation Rates, $cm/10^3$ yr
Lowlands	
Climate with cold winter	2.9
Intermediate maritime climate	2.7
Hot-dry climate (New Mexico)	1.2
Hot-moist climate with dry season	3.2
Equatorial climate (dense rain forest)	2.2
Mountains	
Semihumid periglacial climate	60.4
Extreme nival climate (SE Alaska)	80.0
Climate of Mediterranean high mountain chains	44.9
Hot-dry climate (SW United States)	17.7
Hot-moist climate (Mexico)	9.2

(a) Bloom (1978)

TABLE 3.2. Drainage Basin Denudation Rates, Based on Effective Precipitation[a]

	Effective Precipitation, cm	Mean Sediment Yield, 10^3 kg/km^2	Mean Denudation Rate, cm/10^3 yr
Gaging station data[b]	25	240	9
	25 to 38	280	10
	38 to 51	200	7
	51 to 76	200	7
	76 to 102	140	5
	102 to 152	80	3
Reservoir data [c]	20 to 23	500	19
	25	420	16
	28	530	20
	36 to 64	400	15
	64 to 76	510	19
	76 to 97	280	10
	97 to 102	200	7
	102 to 140	170	6
	140 to 254	160	6

(a) Schumm (1963)
(b) Average drainage area of 3800 km^2
(c) Average drainage area of 75 km^2

Entrenchment and aggradation are associated with stream erosion and bed-loading, respectively. The sediment load and energy potential of the water determine if sediments will be removed or deposited. Within the time frame specified, these factors have litte relevance, unless mill tailings piles are sited in the immediate vicinity of an active stream bed.

Several additional variables that could significantly alter erosion rates must be considered. The most obvious is man's impact on the environment. Current erosion rates may be several times higher than in the past as a result of agricultural activity (Douglas 1967). Another variable that could affect erosion is ashfall such as that produced by the volcanic Mt. St. Helens in Washington. Significant amounts of ash could reduce vegetation and soil permeability, which in turn would accelerate runoff. Local catastrophic events that could alter a stream course, such as faulting or landslides, could also affect local erosion patterns. All of these factors should be considered when modeling 1000-yr changes in geomorphology.

4.0 IDENTIFICATION OF STUDY REGIONS

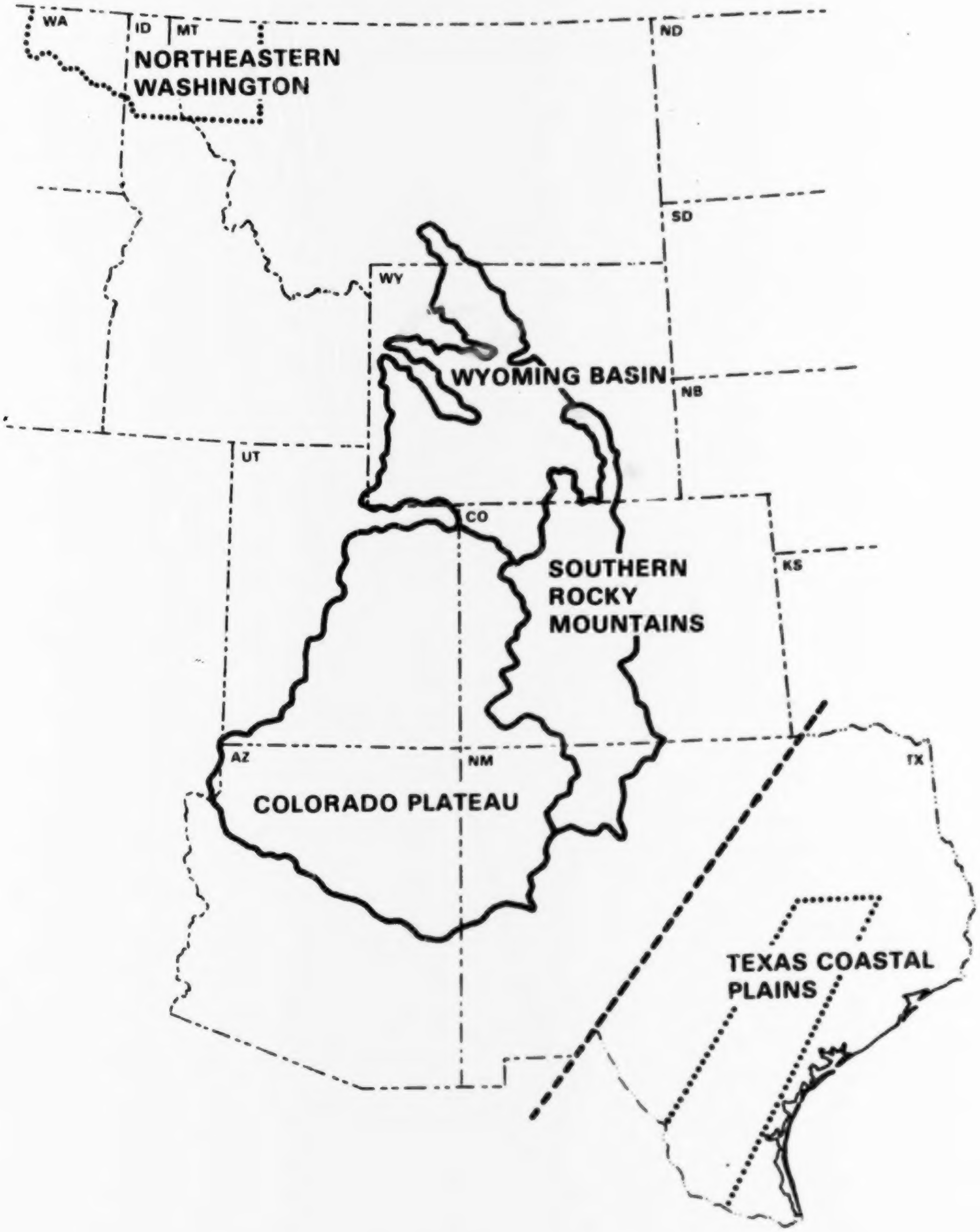
Most domestic uranium mills are located in three regions: west-central New Mexico, central Wyoming, and Utah/Colorado near the Four Corners area. Smaller regional production center groupings are located on the Texas Gulf Coast and in northeastern Washington. In addition, several individual uranium mills are located in areas away from these regional groupings.

Local and regional data on environmental conditions at domestic uranium mills have been evaluated for the following five regions (see Figure 4.1):

- Northeastern Washington
- Wyoming Basins
- Colorado Plateau
- Texas Gulf Coast
- Southern Rocky Mountains.

These geographic study areas correspond to regions defined by the Department of Energy's National Uranium Resource Evaluation Program (Argonne National Laboratory 1979). The Colorado Plateau and Southern Rocky Mountains study regions coincide with natural physiographic provinces. Boundaries of the remaining study areas have been drawn to group uranium mills into broad regions, even though they do not necessarily correspond to physiographic provinces.

The following sections discuss environmental conditions in each of the identified regions, describe the mill sites in the region, and show how particular site features and environments may affect decisions regarding stabilization requirements.


WA
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CO
SOUTHERN
ROCKY
MOUNTAINS
KS
AZ
NM
TX
COLORADO PLATEAU
TEXAS COASTAL
PLAINS

FIGURE 4.1. The Five Study Regions and Corresponding Physiographic Provinces (The boundaries of the study regions are shown as dotted lines if they are different from those of the physiographic provinces.)

5.0 NORTHEASTERN WASHINGTON

Uranium-producing areas of northeastern Washington (see Figure 4.1) lie near the confluence of the Spokane and Columbia Rivers in the western foothills of the Rocky Mountains. Currently, only two uranium mills are active in the region: the Ford Uranium Mill (Dawn Mining Co.) near Ford, Washington, and the Sherwood Uranium Mill (Western Nuclear) on the Spokane Indian Reservation a few miles to the west. Although regional exploration has been active, no new mills are planned.

The region's semiarid climate is characterized by low precipitation and wide temperature extremes. Winds are moderate and tornados rare. Because the region is between the Cascade and Rocky Mountain ranges, and within 320 km (200 miles) of a tectonic plate boundary, seismic and geothermal activity is high compared to other domestic uranium-producing centers.

5.1 REGIONAL CLIMATOLOGY AND METEOROLOGY

The uranium mills of northeastern Washington lie in a semiarid continental climate. Annual temperature variations are extreme, fluctuating over 50°C. Summer temperatures can exceed 38°C, and winter lows below -30°C are common. Freeze-free days range from 120 to 150/year.

Annual precipitation in the region ranges between 30 to 50 cm (12 to 20 in.), with about 70% falling between October and March. Of this annual precipitation, approximately half occurs as snow. Pan evaporation ranges from 102 to 165 cm (40 to 65 in.)/yr.

Wind data collected at the Spokane Airport, 40 km (25 miles) to the southeast, indicate that winds are typically south-southwesterly. Southwesterly winds are moderate, but can gust up to 24 m/sec (60 mph). Mean annual wind speed is about 3 m/sec (8 mph). Destruction from storms in northeastern Washington may be attributed to high winds and occasional thunderstorms. Tornados in the area are extremely rare.

5.2 REGIONAL HYDROLOGY

Uranium-producing centers of northeastern Washington are located between two major drainages: the Spokane River and the Columbia River. The Spokane River drainage serves as a catchment to virtually all surface water near the two mine and mill sites. Ground water in the area is common because of extensive glacial deposits of high permeability.

Chamokane Creek, with a mean discharge of 1.5 m^3/sec (53 ft^3/sec), is the dominant surface drainage near the Ford Mill site. The Sherwood Mill is located approximately one mile south of the junction of Blue Creek and Oyachen Creek, which has a drainage area of 5100 ha (12,600 acres) and an average annual water yield of 440 ha-m/yr (3700 acre-ft/yr). An intermittent drainage within the Sherwood Mill site has an annual average drainage of 40 ha-m/yr (330 acre-ft/yr) (U.S. Department of the Interior 1976).

A substantial amount of ground water occurs beneath Walker's Prairie in the vicinity of the Ford Mill. Glacial materials of the prairie are estimated to have an effective storage capacity of about 1800 ha-m (15,000 acre-ft) of water. A subterranean spring near the mill has a consistent flow rate of over 0.7 m^3/sec (25 cfs) (Washington State Department of Social and Health Services 1980). Because the Sherwood Mill does not lie within a ground-water basin, ground-water yields are low. Ground water is available in glacial alluvium above impermeable basement rocks.

5.3 REGIONAL SOILS

Most soils in northeastern Washington were formed within the last 12,000 years since glacial retreat. Because of their relatively young age and glacial influence, the soils tend to be a sandy loam with low organic content. Mollisols frequently exist in the uranium-producing regions and grade into Inceptisols in a northeasterly direction.

Portions of the Ford Mill site overlie the Springdale series, a soil typical of the area. In this soil phase, a 15-cm (6-in.) subsurface layer of pale brown, stony, sandy loam grades into gravely loam, coarse sands, and cobbly, gravelly coarse sand below. Moisture content of the soils tends to be low because of a lack of organic matter. Where soils locally contain loess and volcanic ash, the moisture-holding capacity is increased.

5.4 REGIONAL GEOLOGY AND GEOMORPHOLOGY

Regional geology of northeastern Washington is characterized by Precambrian metasediments with large granitic intrusions of Cretaceous to early Tertiary age. Clastic and pyroclastic sediments of Tertiary age are also present. Structurally, the region is a series of complex mountain belts and fault-controlled basins.

At Ford Mill's Midnite Mine, uranium ore occurs as veinlets in a host rock of schist, phyllite, and quartzite, along a contact with granitic intrusives. Western Nuclear's Sherwood Mill, south of the Midnite Mine, is producing uranium from sandstone and arkosic conglomerate. These stratiform deposits are underlain by granitic intrusives and overlain by andesite volcanics. Local structures in the Stevens County uranium-producing area include faulting along the Spokane River graben and the deformation of overlying sediments by granitic intrusives. Topography of the mining areas consists of eroded plateau basalt cliffs and rounded granitic hills. Glacial moraines and flood deposits have significantly influenced local geomorphology.

5.5 REGIONAL SEISMICITY AND GEOTHERMAL POTENTIAL

Although local uranium-producing areas of Washington have been seismically inactive during recorded history, the surrounding region has a relatively high incidence of earthquakes and fault zones. Orogenic deformation has resulted in faulting along the Cascade Range and Rocky Mountains that bound the mining region, which also lies within 320 km (200 miles) of a tectonic plate boundary. In addition, the region may still be experiencing adjustments from glacial unloading.

Historic earthquake data indicate that at least one earthquake of intensity IV, Modified Mercalli (MM), has occurred within 48 km (30 miles) of Washington uranium mill sites. Also, at least six earthquakes of intensity VI (MM) have been reported within 145 km (91 miles), one of which was within 72 km (45 miles). Several earthquakes of intensity VII and VIII (MM) have been recorded 320 km (200 miles) to the west where the Juan de Fuca plate is being subducted under the North American plate (U.S. Department of the Interior 1976).

Four zones of faulting have been identified within a 160-km (100-mile) radius of the uranium-producing sites. Although earthquakes in the area have not been correlated with specific faults, epicenters may be related to zones of faulting (U.S. Department of Interior 1976).

5.6 MILL SITE CHARACTERISTICS

Two mills are currently operating in Washington--the Ford Mill near Ford, and the Sherwood Mill near Wellpinit. Both mills are located in Stevens County. Together they process about 2250 MT/day (2475 tpd). Important physical characteristics of these mills are summarized in Table 5.1. Topographic features of these mills are illustrated in the Appendix.

5.6.1 Ford Uranium Mill (Dawn Mining Co.)

The Ford Uranium Mill is located about 40 km (25 miles) northwest of Spokane, near the Spokane Indian Reservation. The mill incorporates a two-stage agitated acid leach. The uranium is removed from the leach solution through ion exchange, and the resulting pregnant liquor is treated with lime to precipitate iron, and with ammonia to precipitate uranium. Waste is neutralized with lime and is pumped to a tailings pond. The tailings pond is an unlined conventional impoundment, roughly rectangular in shape, divided into three compartments by natural material embankments. Because the pond is nearly full, a new subgrade disposal area is being developed. A 20-m (65-ft) deep pit with a surface area of 11 ha (28 acres) will be excavated. According to current reclamation plans, the tailings will be allowed to dry and the surface will be graded to enhance drainage. A 16-m (52-ft) layer of clay will be placed over the surface and compacted, followed by an additional 2.4 m (8 ft) of sands and gravel (Washington Department of Social and Health Services 1980).

5.6.2 Sherwood Uranium Mill (Western Nuclear)

The Sherwood Uranium Mill is operated about 64 km (40 miles) northwest of Spokane on the Spokane Indian Reservation. The Sherwood Project began in 1978, using conventional, agitation leach-solvent extraction methods to process

TABLE 5.1. Physical Characteristics of Mills in Eastern Washington

Site Characteristics	Ford Mill(a)	Sherwood Mill(b)
Location	117° 50'W 47°53'N	118°6'N 47°53'W
Type of Pond	A, B	A
Tailings Area (ha)	39	17
Tailings Dimensions (m)	A = 610 x 1070 B = 275 x 275	915 x 610
Embankment (Pond Type A):		
Material	Earthen	Sand and Coarse Tailings
Slope	3H:1V	2.5H:1V
Height	NA	30
Mill Elevation (MSL--m)	518	610
Leach Process	Acid	Acid
Ore Process Rate (MT/day)	450	1800

(a) Washington State Department of Social and Health Services (1980)
(b) U.S Department of the Interior (1976)

KEY

Type of Pond: A--above ground, with dikes
B--natural or excavated pits
C--lined cells or trenches
ha--hectare
m--meter
H:V--horizontal:vertical
NA--not available
MSL--mean sea level
MT-- metric tonne

uranium ore. After solvent extraction, the pregnant organic is stripped with ammonia and the uranium from the pregnant strip solution is precipitated with ammonia. Waste is neutralized with lime and pumped to the tailings pond. After the solids have settled, the liquid portion of the tails are recycled, treated, and sent to an evaporation pond.

The tailings pond occupies 17 ha (42 acres), is lined with hypalon®, and is located in a valley with moderately inclined walls. The pond's impoundment dike extends 850 m (2800 ft) with a crest of 6 m (20 ft). The dam is constructed of alluvial sand and coarse tailings (U.S. Department of the Interior 1976).

5.7 PRECIPITATION AND POTENTIAL FLOOD STRESSES

Important flood parameters are summarized in Table 5.2. Precipitation information cited in the references was obtained from weather data for Spokane and Wellpinit, Washington. The flood risk for mills in eastern Washington is quite low because both mills are located at elevations of 30 m (100 ft) or more above the nearest stream. The Grand Coulee Dam is several kilometers upstream of the Sherwood Mill. The large flow associated with dam failure would not affect the tailings pond.

The most important water erosion parameter is surface runoff. Because of the high permeabilty of the soil and moderate rainfall, the effect of surface runoff is reduced. However, both tailings impoundments are built across natural basins and thus are susceptible to erosion from surface runoff. No estimate of maximum surface runoff is given for the Ford Mill. However, for the 325-ha (800-acre) area upstream of the Sherwood tailings dam, the maximum 100-year flood discharge occurring as surface runoff is 9 m^3/sec (325 cfs). A Probable Maximum Flood (PMF) analysis was not available. Diversion ditches currently route the runoff around the tailings. Over the long term, the integrity of the diversion ditches may determine the amount of surface runoff to which the Sherwood tailings area is exposed. Drainage features for the Sherwood Mill area are shown in Figure 5.1 (U.S. Dept. of Interior 1976).

5.8 EOLIAN DISRUPTION POTENTIAL

Important parameters for estimating eolian disruption are shown in Table 5.3. Winds in eastern Washington are moderate with about 32 m/sec (80 mph) extremes and a very low tornado risk (Nelson and Shepherd 1978). The prevailing wind direction is from the southwest or west-southwest during spring and summer and from the northeast in winter. All of the record high wind speeds have been set by southwest or west winds. The Sherwood Mill has lessened the effect of eolian erosion by orienting the long axis of the tailings in a west-southwest direction, with the dam on the southwest side. The long axis of the larger above-ground tailings pond at the Ford Mill is oriented east-west with tailings dikes on all sides. The slope of these dikes is approximately 3H:1V. The slope of the site is approximately 2%, trending downward to the north or northwest.

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TABLE 5.2. Flooding Parameters for Mills in Eastern Washington

Parameters	Ford Mill[a]	Sherwood Mill[b]
Nearest Stream	Chemokane Creek	Spokane River
Drainage Area for Stream (km^2)	460	NA
Distance to Stream (m)	305	2400
Stream Elevation (MSL--m)	500	490
Site Elevation (m)	530	635
Elevation Difference (m)	30	145
Stream Flow (m^3/sec):		
Mean	1.4	3,100
Maximum	NA	20,300
Proximity to Gaging Station (km)	9.6	9.6
Surface Runoff (m^3/sec):		
Mean Annual	NA	NA
Maximum	NA	9
Slope of Surrounding Area (%)	5 to 15	11
Vegetation Density	High	Moderate
Vegetation Type	Pine and grasses	Pine, grasses, and brush
Soil Runoff Potential	Low	High
Precipitation:[c]		
Mean Annual (cm)	38 to 58	38 to 58
Maximum Recorded (cm)	NA	NA
Snowfall (cm)	116 to 147	116 to 147
Period of Record (yr)	30 to 40	30 to 40
Evaporation:		
Mean Annual (cm)	NA	139
Period of Record (yr)	NA	20
PMP	NA	NA
Tailings Pond:		
Drainage Area (ha)	NA	324
Underlying Geology	Deep glacio-fluvial sands and clays underlain by basalt	Deep alluvial sands underlain by granite

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(a) Washington State Department of Social and Health Services (1980)
(b) U.S. Department of the Interior (1976)
(c) U.S. Weather Bureau, Spokane and Wellpinit, Washington, climatological data

KEY

NA--not available
MSL--mean sea level
m--meter
sec--second
km--kilometer
cm--centimeter
h--hour
ha--hectare
PMP--Probable Maximum Precipitation

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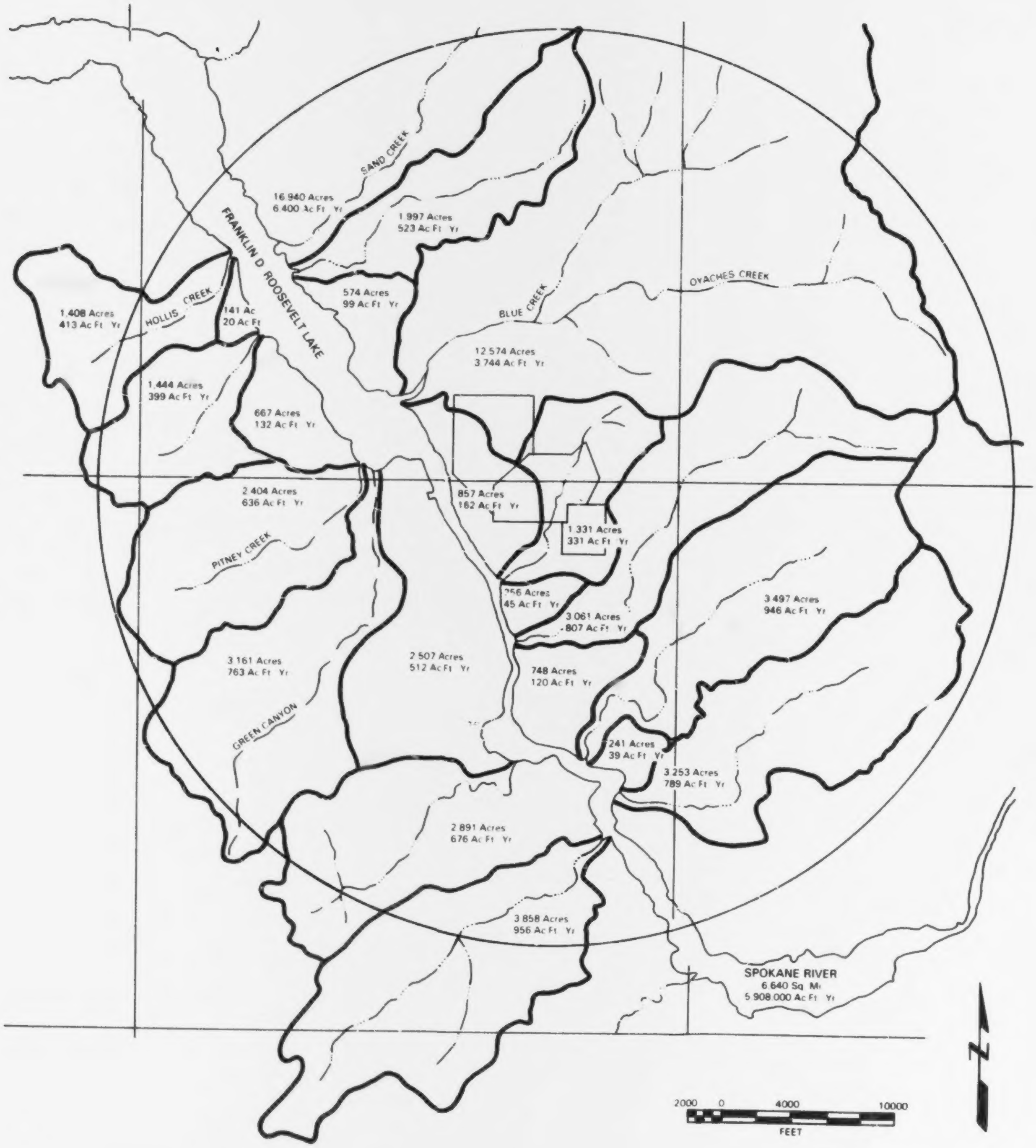
SAND CREEK
16 940 Acres
6 400 Ac Ft Yr
1 997 Acres
523 Ac Ft Yr
FRANKLIN D ROOSEVELT LAKE
1 408 Acres
413 Ac Ft Yr
HOLLIS CREEK
141 Ac
20 Ac Ft
574 Acres
99 Ac Ft Yr
BLUE CREEK
OYACHES CREEK
12 574 Acres
3 744 Ac Ft Yr
1 444 Acres
399 Ac Ft Yr
667 Acres
132 Ac Ft Yr
2 404 Acres
636 Ac Ft Yr
857 Acres
162 Ac Ft Yr
1 331 Acres
331 Ac Ft Yr
PITNEY CREEK
256 Acres
45 Ac Ft Yr
3 061 Acres
807 Ac Ft Yr
3 497 Acres
946 Ac Ft Yr
3 161 Acres
763 Ac Ft Yr
2 507 Acres
512 Ac Ft Yr
748 Acres
120 Ac Ft Yr
GREEN CANYON
241 Acres
39 Ac Ft Yr
3 253 Acres
789 Ac Ft Yr
2 891 Acres
676 Ac Ft Yr
3 858 Acres
956 Ac Ft Yr
SPOKANE RIVER
6 640 Sq Mi
5 908 000 Ac Ft Yr
N
2000
0
4000
10000
FEET

FIGURE 5.1. Surface Water Drainage Features for Sherwood Mill Area

TABLE 5.3. Eolian Disruption Parameters for Mills in Eastern Washington

Parameters	Ford Mill[a]	Sherwood Mill[b]
Historical Wind Data (m/sec):		
Mean Velocity	3.8	3.8
Maximum Recorded Gust	23	23
Maximum 100-Yr Gust	32	32
Angle Between Mean Wind Direction and Long Axis of Pond	45° to 60°	0°
Width of Tailings Pile Along Wind Direction (m)	915	610
Location of Dams in Relation to Pond	All Sides	South, Southwest
Storm Potential:		
Tornado Frequency	Low	Low
Tornado Velocity	NA	NA
Soil Characteristics:[c]		
Slope Range (%)	0 to 20	0 to 40
Surface Texture	Coarse	Coarse
Depth to Bedrock (cm)	>150	>40 to 80
Depth to Water Table (cm)	>150	>150
Permeability	Rapid	Moderate-Rapid
Soil Erodibility	Low	High
Wind Erosion Potential	High	High
Runoff Potential	Low	High

(a) Washington State Department of Social and Health Services (1980)
(b) U.S. Department of the Interior (1976)
(c) Soil information for the mills was obtained from:

- Soil maps for mill sites in Stevens County, Washington Soil Conservation Service, Colville, Washington
- Draft: Environmental Impact Statement, Ford Mill, Washington State Department of Social and Health Services
- Final Environmental Statement, Sherwood Mill, U.S. Department of the Interior Bureau of Indian Affairs, Portland Area

KEY

m--meter
sec--second
NA--not available
cm--centimeter

5.9 SEISMIC AND GEOTHERMAL DISRUPTION POTENTIAL

Important parameters for estimating geothermal or seismic disruption potential are shown in Table 5.4. Eastern Washington is an area of moderate to moderately high seismic risk. A small risk results from the volcanic system 160 km (100 miles) away. Both mills are near fault zones that indicate earthquake activity. Based on a 48-km (30-mile) fault length, the maximum potential earthquake magnitude within 16 km (10 miles) of the site is 6 on the Richter scale. The duration of strong ground shaking is predicted to be 15 sec (Nelson and Shepherd 1978). Peak ground acceleration is estimated to be 0.1 g (U.S. Geological Survey 1970).

TABLE 5.4. Seismic and Geothermal Disruption Parameters for Mills in Eastern Washington

Parameters	Ford Mill(a,b)	Sherwood Mill(b,c)
Distance to (km):		
Intensity V (mm) Earthquake	64	72
Fault Longer than 10 km	11	16
Hydrothermal System (1 to 10 x 10^{18} J)	173	154
Hydrothermal System (>10 x 10^{18} J)	480	480
Igneous System (>100 x 10^{18} J)	173	154
Igneous System (100 to 1000 x 10^{18} J)	480	480
Igneous System (>1000 x 10^{18} J)	1060	1060
Tailings Dam:		
Seismic Stability (g)	NA	0.1

(a) Washington State Department of Social and Health Services (1980)
(b) U.S. Geological Survey (1979)
(c) U.S. Department of the Interior (1976)

KEY

km-- kilometer
g--gravity (acceleration due to)
NA--not available

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6.0 WYOMING BASINS

Wyoming uranium deposits occur in a natural physiographic province of basins and ranges that formed with the Rocky Mountains (see Figure 4.1). Eleven uranium mills are currently active in central and east-central Wyoming.

The area climate is semiarid with low precipitation and a wide seasonal variation of temperatures. Severe thunderstorms and snowstorms are common. Winds are moderate to high and occasionally spawn small tornados.

Interior portions of the region are tectonically stable, with the highest risk of seismic disruption restricted to the boundaries of the province. Geothermal potential within the uranium-producing regions is insignificant. Wind erosion and anomalous flooding have the greatest potential for mill tailings disruption.

6.1 REGIONAL CLIMATOLOGY AND METEOROLOGY

Wide seasonal temperature variations and arid to semiarid climatic conditions characterize the Wyoming Basins. Moderately strong winds in the region average from 5 to 7.5 m/sec (12 to 18 mph) and prevail from the west-southwest. Maximum gusts average around 25 m/sec (60 mph), but can reach 35 m/sec (86 mph). Summer thunderstorms occasionally spawn small, short-lived tornados.

Average annual precipitation in the region ranges between 30 to 40 cm (12 to 16 in.); most of it falls in spring and summer as wet snow and rain. Pan evaporation averages 100 to 180 cm (40 to 70 in.) per year. Seasonal temperatures range from summer highs of about 38°C to winter lows of about -40°C (Argonne National Laboratory 1979).

6.2 REGIONAL HYDROLOGY

Surface-water resources in the Wyoming Basins include four major drainages: the Powder, North Platte, Wind-Bighorn, and Belle Fourche Rivers. In addition, numerous intermittent streams dissect the region. Strata underlying the basins act as conduits and often contain ground water. Also, water is often contained in unconsolidated material near the surface of the basins. Because most of the uranium mills in the region are sited away from major surface drainages, tributaries become more important to the study. Accordingly, relevant drainages will be considered in detail as specific sites are addressed.

Basement sediments of the region typically dip steeply into the basins, resulting in very deep confined ground-water aquifers. Ground water in shallow unconfined aquifers usually occurs under water table conditions with little to no artesian head (Argonne National Laboratory 1979).

6.3 REGIONAL SOILS

Soils in the Wyoming Basins region fall into the two general classifications of Aridisols and Entisols. Soils of both types formed under arid to semiarid conditions and have low organic content. Aridisols are generally characterized by a basal layer of calcium and magnesium carbonate overlain by an accumulation of argillaceous clay. The surface horizon is usually fine to medium textured, with periods of continuous moisture for less than three months. Endisols have poorly defined horizons and higher salt content (Buol, Hole and McCraken 1973).

Although detailed soil surveys have not been completed for Wyoming, site-specific data on soil are available from environmental impact statements for individual mills. Natural disruptive factors that are influenced by soil characteristics were identified from these sources.

6.4 REGIONAL GEOLOGY AND GEOMORPHOLOGY

The Wyoming Basins region, which includes as many as 10 basins, formed during the Laramide orogeny approximately 100 million years ago. Typically, the basins are underlain by Paleozoic and Mesozoic marine and continental sedimentary rocks. Subsequent erosion of adjoining ranges during Tertiary time filled much of the basins with continental sediments.

Clastic deposits within the basins consist of fine-grained sand and silt reworked from older strata. Wedges of coarse arkosic sand and gravel from Precambrian granitic mountain cores are also present. In addition, abundant volcanic material was deposited during Tertiary time and is thought to be the source of uranium, most of which occurs in sandstone host rocks.

The system of Wyoming Basins is a relatively flat area that separates the northern Rocky Mountains from the southern Rocky Mountains. Elevations range from 1800 m to 2400 m (5900 to 7900 ft) with an average elevation of 2100 m (6900 ft). Playas, sand dunes, badlands, and rimrock escarpments are common throughout the area (Argonne National Laboratory 1979).

6.5 REGIONAL SEISMICITY AND GEOTHERMAL POTENTIAL

The Wyoming Basins are included in a region of low seismic risk that extends over the entire Midwest. No earthquakes greater than intensity VI (MM) have been recorded in the uranium-producing region (Coffman and Von Hake 1973). The nearest area of moderate-to-high seismic risk is along the Wyoming-Idaho border. Wyoming is bounded by two areas of seismic activity defined as having at least four intensity VII (MM) or greater events per 10 years per square degree. One area parallels the border with Idaho and extends into the Yellowstone area. The other area extends up from Colorado into the Medicine Bow Mountains. Remaining areas of Wyoming are divided into regions of "lesser seismicity" or "no seismicity." Uranium-producing areas fall into these latter two categories (Kaiser Engineers, Inc. 1979).

No igneous or high-temperature hydrothermal systems are known to underlie the region. Hot springs near Thermopolis, in the central part of the state, contain waters with a subsurface temperature between 50°C to 150°C. In addition, a local area east of Casper has the potential to produce water with temperatures up to 90°C Also, several small areas that may contain water at temperatures up to 50°C are scattered throughout the uranium-producing region (U.S.G.S. 1979).

6.6 MILL SITE CHARACTERISTICS

Eleven mills operate in the Wyoming Basins. Most of the mills are located in three major regions: 1) Shirley Basin, 2) Gas Hills, and 3) Powder River Basin. Together these mills process about 20,500 MT/day (22,600 tpd) of ore. Important physical characteristics of these mills are summarized in Table 6.1. Topographic maps for these mills are shown in the Appendix.

6.6.1 East Gas Hills Mill (Union Carbide Corp.)

The East Gas Hills Mill is located about 104 km (65 miles) west of Casper, Wyoming. The mill uses an acid leaching process (RIP-Eluex System) to remove uranium from the ore. As of January 1980 the mill has a capacity of 1250 MT/day (1375 tpd).

Waste was formerly deposited into a 60-ha (148-acre), above-grade tailings pond, using an embankment with a maximum height of 14 m (45 ft). Since January 1980, tailings are deposited in a depleted open-pit mine. Three feet of clay line the 11-ha (26-acre) pit bottom. A second mine pit will be available in 1982. To reclaim the pits, at least 1 ft of clay and 3 to 6 m (10 to 20 ft) of overburden will be placed over the tailings. After filling to natural grade level, the cover will be blended to the contour of the landscape (Dames and Moore 1979).

6.6.2 Gas Hills Mill (Federal American Partners)

At the Federal American Partner (FAP) Mill, about 80 km (50 miles) east of Riverton, Wyoming, uranium is processed using acid leach, sand-slime separation, resin-in-pulp (RIP) ion exchange, and solvent extraction (SX). After stripping the pregnant solution from the SX circuit with ammonium sulfate, the uranium is precipitated with anhydrous ammonia. Mill tailings are pumped to a conventional, above-ground impoundment formed by a peripheral earth dam.

Future tailings will be deposited in a below-grade, mined-out pit. The pit is underlaid with a continuous, impervious mudstone layer. After a post-operational drying period, the 10-ha (24-acre) pit will be covered with overburden consisting of 20% clay, 18% silt, and 62% sand. Following backfilling of overburden, grading will be carried out so that the final slope is 3H:1V. The surface will be spread with topsoil and revegetated (Kaiser Engineers 1979).

TABLE 6.1. Physical Characteristics of Mills in the Wyoming Basins

Site Characteristics	Shirley Basin		Gas Hills			Powder River Basin				Others	
	Petrotomics(a)	Pathfinder(b)	UCC(c)	Pathfinder(d)	FAP(e)	Rocky Mtn. Energy Co.(f)	Exxon(g)	TVA(h)	Kerr-McGee(i)	Western Nuclear(j)	Minerals Exploration(k)
Location	106°11'W 42°20'N	106°11'W 42°22'N	107°30'W 42°50'N	107°36'W 42°48'N	107°37'W 42°47'N	105°38'W 43°16'N	105°30'W 43°4'N	105°28'W 43°1'N	105°42'W 43°5'N	107°47'W 42°31'N	107°53'W 42°3'N
Type of Pond	A	A	A,B	A	A,B	A	A	C	A	A	B
Tailings Area (ha)	65	93	A=60 B=10	56	A=18 B=24	61	100	38	NA	93	100
Tailings Dimensions (m)	915 x 760	1100 x 760	A=1070 x 760 B=915 x 213	3050 x 610	A=190 x 260 B=540 x 540	915 x 460	1600 x 1700	600 x 2600	NA	1220 x 610	NA
Embankment (Pond Type A):											
Material	Bentonitic Clay, Sand and Mine Overburden	Sandy Clay Core, Earthen	NA	Clay Core, Earthen	Earthen	Earthen and Rock	Clay Core, Earthen	--	NA	Coarse Tailings	--
Slope	2H:1V	2H:1V	2.5H:1V	1.5H:1V	NA	3H:1V	2H:1V	--	NA	5H:1V	--
Height (m)	23	19	14	33	NA	18	38	--	NA	37	--
Site Elevation (MSL--m)	2165	2165	2074 to 2150	1952	1980	1555	1616	1543 to 1713	1708	1930	2013
Leach Process	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid
Ore Process Rate(l) (MT/day)	1365	1600	1274	2500	900	1820	2720	1803	2275	1550	2730

(a) Chen and Associates, Inc. (1980)
(b) Atomic Energy Commission (1974)
(c) Dames and Moore (1979)
(d) U.S. Nuclear Regulatory Commission (1977a)
(e) Kaiser Engineers, Inc. (1979)
(f) U.S. Nuclear Regulatory Commission (1977b)
(g) Exxon Company, U.S.A. (1973)
(h) U.S. Nuclear Regulatory Commission (1977c)
(i) Kerr-McGee Nuclear Corp. (1977)
(j) U.S. Nuclear Regulatory Commission (1980a)
(k) U.S. Nuclear Regulatory Commission (1978)
(l) U.S. Nuclear Regulatory Commission (1980b)

KEY

Type of Pond: A--above ground, with dikes
B--natural or excavated pits
C--lined cells or trenches
ha--hectare
NA--not available
m--meter
MSL--mean sea level
MT--metric tonne

6.6.3 Gas Hills Mill (Pathfinder Mines)

The Gas Hills Uranium Mill (formerly Lucky Mc) is located about 40 km (25 miles) northeast of Jeffrey City, Wyoming. The mill uses a two-stage acid leach to extract the uranium. The leach liquors are clarified and the uranium is recovered through ion exchange. After solvent extraction, the uranium is precipitated with ammonia.

The tailings retention system consists of five tailings ponds encompassing 55 ha (135 acres). The ponds are situated sequentially in a small natural ravine north-northwest of the mill. Clay-core dams provide protection against seepage. The average tailings depth is expected to increase to 33 m (110 ft) by the end of operations. After a post-operational drying period, all contaminated areas will be buried under a layer of clay 0.6 m (2 ft) thick. The clay-covered areas will be overlain with 1 to 2 m (3 to 6 ft) of topsoil, and the pond surface will be revegetated (U.S. Nuclear Regulatory Commission 1977a).

6.6.4 Split Rock Mill (Western Nuclear)

The Split Rock Mill is located about 3 km (2 miles) north of Jeffrey City, Wyoming, and 64 km (40 miles) northwest of Riverton. The ore is ground and leached with sulfuric acid and the leach liquor is passed through ion exchange resins to extract the uranium. The uranium is stripped from the resin by a concentrated salt solution. The purified product is precipitated with ammonia and is calcined.

The radioactive wastes are deposited in an impoundment dam east-southeast of the mill. The upstream face of a tailings beach was created by the settling of coarse tailings near the point of discharge. The fan-type embankment was built up by relocating the tailing spigot from time to time. After a release incident in April, 1977, a retention embankment of compacted tailings and dune sand was extended from the south to the north valley walls to a height of 20 m (67 ft).

During the coming 20 years of operating life, a retention dam composed of the coarse fraction of the tailings will be incrementally constructed to a height of 37 m (123 ft). The downstream slope of the embankment will be maintained at a slope of 5H:1V. During the post-operational period of the mill, the 93-ha (230-acre) area will be allowed to dry. The surface will be contoured similiar to the surrounding area and covered with clay from the Cody shale formation. The clay will be compacted to 0.6 m (2 ft) and covered with local soils (dune sands) (U.S. Nuclear Regulatory Commission 1980a).

6.6.5 Bear Creek Mill (Rocky Mountain Energy Co.)

The Bear Creek Mill is located about 72 km (45 miles) northeast of Casper, Wyoming, and has been operational since September 1977. The mill produces about 1800 MT/day (1980 tpd). Through acid leach methods, the uranium is further concentrated by a solvent extraction process and is stripped from the organic solution with ammonium sulfate. The uranium is precipitated with anhydrous ammonia. An 18 m (60 ft) high by 460 m (1500 ft) long earth and rockfill dam forms the 60-ha (150-acre) tailings retention area for depositing the wastes. Built into a natural basin, the dam slopes 3H:1V on the downstream side and 2.5H:1V on the upstream side. When milling operations cease, contaminants will be dredged to the edge of the coarse tailings fraction, reducing the area occupied by tailings to 40 ha (100 acres). The area will be covered to a depth of 1.8 m (6 ft) with fill material and at least 15 cm (6 in.) of topsoil. Diversion ditches will be constructed to protect the area from surface runoff (U.S. Nuclear Regulatory Commission 1977a).

6.6.6 Highland Mill (Exxon Corp.)

Exxon's Highland Mill is located 97 km (60 miles) northeast of Casper, Wyoming, in an area of rolling hills and valleys. The mill processes approximately 2720 MT/day (2990 tpd) of ore using conventional acid-leach, solvent-extraction, uranium ore processing. A clay-core, earthfill dam retention system serves as a collection and storage system for the liquid and solid process wastes. The tailings system is located in a natural valley and occupies an area of 10 ha (25 acres). In the final stages, the dam will be 38 m (125 ft) high, and 550 m (1800 ft) long. After a post-operational drying period, the pond will be covered with 46 cm (18 in.) of sandstone and siltstone, followed by 15 cm (6 in.) of topsoil. The soil will be graded so that runoff will be directed to an overflow weir. The overflow weir and areas where runoff occurs will be riprapped. The rest of the tailings area will be revegetated. Diversion ditches will protect the area from surface runoff (Exxon 1973).

6.6.7 Shirley Basin Mill (Pathfinder Mines Corp.)

The Pathfinder's Shirley Basin uranium mill is located 72 km (45 miles) south of Casper, Wyoming. The mill is an acid leach, resin ion exchange, uranium ore processing plant with a design capacity of 1600 MT/day (1760 tpd) of ore. The tailings are deposited in a pond with a dam on one side. The ultimate dam is being constructed in three stages, with a final planned height of 19 m (65 ft), a total length of 1860 m (6100 ft), and a crest width of 6 m (20 ft). The dam is made of compacted clay-like sand and coarse tailings with slopes of 2H:1V and 2.5H:1V on the upstream and downstream faces, respectively. After termination of operation, the area will be backfilled and revegetated (Atomic Energy Commission 1974).

6.6.8 Shirley Basin Mill (Petrotomics Co.)

The Petrotomics Shirley Basin Mill is located about 104 km (65 miles) south of Casper, Wyoming. The mill began operations in 1962 and currently processes ore at an average rate of 1400 MT/day (1540 tpd). The ore is crushed and leached with sulfuric acid. Other major process steps include solvent extraction and precipitation of uranium with anhydrous ammonia.

Radioactive waste is pumped to a tailings area formed by damming a natural ravine. The current tailings embankment has a crest length of 1950 m (6400 ft), a top width of 15 m (50 ft), and a maximum height of 23 m (75 ft).

The embankment is constructed from a compacted bentonitic clay and sand material underlain by claystone. Upstream and downstream slopes of the dams are 2H:1V. Reclamation will probably consist of backfilling and revegetating the area (Chen and Associates, Inc. 1980).

6.6.9 South Powder River Basin Mill (Kerr-McGee Nuclear Corp.)

The Kerr-McGee South Powder River Basin Mill will be located 26 km (16 miles) northwest of Douglas, Wyoming. Milling operations will consist of semi-autogenous milling to grind the sandstone ore, acid leaching, counter current decantation, solvent extraction, stripping with ammonium sulphate, and precipitation by ammonia gas.

Disposal of tailings will involve the placing of sands and slimes on a slope, which will serve as a solid-liquid separator. The slope is lined with 46 cm (18 in.) of compacted clay. The liquid will be retained by an engineered berm.

As soon as feasible after drying, the tailing area will be covered with compacted clay and several feet of overburden and topsoil. The cover will be tapered to blend into the surrounding topography. The surface should be flat with no major depressions. After contouring and topsoiling, the tailings pond will be revegetated (Kerr-McGee Nuclear Corp. 1977).

6.6.10 Morton Ranch Mill (Tennessee Valley Authority)

The Morton Ranch Mill will be located about 80 km (50 miles) northeast of Casper, Wyoming. The mill will use a conventional acid leach, solvent extraction process to extract uranium from the host ores, after which the uranium is precipitated by the addition of ammonia. The maximum design capacity of the mill is 1800 MT/day (1980 tpd) of ore.

Radioactive solid effluents will be disposed of in the form of a tailings slurry. The tailings impoundment is a clay-lined, depleted mine pit occupying 38 ha (94 acres). The pit bottom is sealed with compacted clay and backfilled above the water table. When the pit is filled to design capacity, the upper layer of solids will be permitted to dry. Then 1.2 m (4 ft) of mine overburden, 0.6 m (2 ft) of compacted clay, another 1.2 m (4 ft) of mine overburden, and 15 cm (6 in.) of topsoil will be emplaced. Current plans call for revegetating the area to establish normal ground cover (U.S. Nuclear Regulatory Commission 1977c).

6.6.11 Sweetwater Uranium Project (Minerals Exploration Co.)

The Sweetwater uranium mill is located about 43 km (27 miles) south of Jeffrey City, Wyoming, and 64 km (40 miles) northwest of Rawlins, Wyoming. Tailings from the Sweetwater Mill are discharged by slurry pipeline to a four-cell impoundment. The cells are excavated above the water table and lined on the bottom and sides with a PVC liner. The tailings, at the cessation of operation, will occupy an area of about 101 ha (250 acres). After a post-operational drying period, the ponds will be covered with 3 to 4 m (10 to 14 ft) of overburden. The cover material will then be contoured to preproject levels (U.S. Nuclear Regulatory Commission 1978).

6.7 PRECIPITATION AND POTENTIAL FLOOD STRESSES

Flood parameters for this region are summarized in Table 6.2. Precipitation information cited in the references was obtained from weather data for Casper, Wyoming, in combination with local data. Lack of precipitation and low surface runoff minimizes flood risk for mills in this area. Over a 1000-year period, however, flood conditions must be expected. Most mill tailings are located on or near intermittent streams, with most of the flow below the surface. Surface flow results from runoff caused by high-intensity precipitation from storms. Reported maximum discharges for a flood with a 1000-year recurrence probability at the Kerr-McGee Mill, for example, are approximately 840 m^3/sec (30,000 cfs).

6.8 EOLIAN DISRUPTION POTENTIAL

Eolian disruption parameters are summarized on Table 6.3. Most of the tailings impoundments in this region are above ground, and are susceptible to wind erosion. As winds are usually from the southwest, ponds with dams on the northern or eastern sides are submitted to the worst erosive conditions. Only the Union Carbide Gas Hills Mill has a dam on the northeast side. Almost all the other mills have dams northwest of the tailings impoundment.

This region is also subject to northerly winds called ground blizzards (strong winds that blow dry snow along the ground--like sand). Extreme winds (100-year probability) for this area are estimated at 40 m/sec (100 mph). Tornado probability is low; however, average tornado velocity is estimated at 97 m/sec (240 mph).

6.9 SEISMIC AND GEOTHERMAL DISRUPTION POTENTIAL

Seismic and geothermal disruption parameters are summarized in Table 6.4. Seismic risk for this area is moderate. All mills are within 80 km (50 miles) of an earthquake epicenter; however, most recorded earthquakes were of low magnitude. Maximum expected ground acceleration was reported to range from 0.04 g to 0.07 g. Volcanic and hydrothermal systems are located 300 or more kilometers away and would have very little influence on the seismic activity of the area.

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TABLE 6.2. Flooding Parameters for Mills in the Wyoming Basins

	Shirley Basin		Gas Hills			Powder River Basin				Others	
Parameters	Petrotomics(a,b)	Path-finder(c,d)	UCC(e,f)	Path-finder(g)	FAP(h)	Rock Mt. Energy Co.(i)	Exxon(j,k)	UNC(l)	Kerr-McGee(m)	Western Nuclear(n,o)	Minerals Exploration(p)
Nearest Stream	Sand Creek	Mine Creek	E. Canyon Creek	Reid Draw	Willow Springs Draw	Bluff Draw	Box Creek, North Fork	Box Creek, South Fork	Willow Creek	Sweetwater River	Battlesprings Draw
Drainage Area for steam (km^2)	NA	NA	NA	3.42	NA	3.3	2.6	NA	41.7	1600 (sq mi)	NA
Distance to Stream (m)	1370	0	213	0	0	0	0	0	0	1600	0
Stream Elevation (m)	2130	2150	2100	1900	1980	1560	1560	1650	1708	1900	2000
Site Elevation (m)	2165	2165	2074 to 2150	1952	1980	1560	1616	1543 to 1713	1708	1930	2000
Elevation Difference (m)	35	15	0	52	0	0	56	0	0	30 m	0
Stream Flow:											
Mean	Intermittent	Ephemeral	NA	NA	Intermittent	Intermittent	NA	NA	NA	4 m^3/sec	Intermittent
Maximum	NA	NA	NA	NA	NA	200 m^3/sec	NA	NA	820 m^3/s	720 m^3/sec	NA
Proximity of Gaging Station (km)	NA	NA	NA	NA	NA	NA	NA	NA	NA	64	NA
Surface Runoff (cm):											
Mean Annual	NA	NA	NA	NA	1.27	1.27	NA	1.27	1.27	NA	NA
Maximum	NA	NA	NA	NA	25 in 24 h	NA	NA	NA	NA	33 in 48 h	NA
Soil Runoff Potential	Moderately Low	Moderately Low	Moderately High	Moderately High	Moderately High	Moderately High	Moderately High	Moderately High	Moderately High	Moderately Low-High	Moderately Low
Slope of Surrounding Area (%)	3	6	3 to 80	6	1 to 20	3 to 30	20 to 50	Gentle	NA	3 to 25	0 to 10
Vegetation Density	Sparse	Sparse	Sparse	Sparse	Sparse	Sparse	Sparse	Sparse	NA	NA	NA
Vegetation Type	Grasses and brush	Grasses and brush	Grasses and brush	Grasses and brush	Grasses and brush	Grasses and brush	Grasses and brush	Grasses and brush	NA	Grasses and sagebrush	Grasses and sagebrush
Precipitation:											
Mean Annual (cm)	28	30	23	24	25	30	30	29	29	30	15 to 40
Maximum Annual Recorded (cm)	39	NA	41	41	NA	NA	NA	NA	41	NA	NA
Mean Snowfall (cm)	203	NA	183	183	NA	NA	89 to 165	188	188	NA	177
Period of Record (yr)	20 to 30	NA	35	35	15	25 to 35	NA	35	25 to 35	NA	25
Evaporation:											
Mean Annual (cm)	117	109	116	NA	107	NA	127 to 152	110	NA	NA	100 to 180
Period of Record (yr)	15	NA	12	NA	NA	NA	NA	NA	NA	NA	NA
PMP	NA	46 in 6 h (point)	19 in 6 h (point)	NA	33 in 24 h (site vicinity)	38 in 18 h (area)	NA	48 in 6 h (point)	25 in 6 h (point)	36 in 48 h (point)	NA
PMT	NA	NA	25 in 1 h (point)	NA	NA	30 in 1 h (point)	NA	NA	NA	11 cm (4100 km^2)	NA
Tailings Pond:											
Drainage Area (ha)	240	165	342	NA	NA	305	NA	157	NA	190	NA
Underlying Geology	Sand from 20 to 75 cm, underlain by sandstone and claystone bedrock	Shallow loam topsoil, underlain by sandstone	Sands and gravels to 12 m, underlain by consolidated sandstone and mudstone	Unconsolidated sands, underlain by sandstone and shales	Shallow alluvium, underlain by impervious siltstone and mudstone	Sand, silt, clay alluvium, underlain by sandstone and claystone	Sand and silt, underlain unconsolidated sandstone and siltstone and shales	3 to 30 m of alluvium, underlain by fine to gained sandstone, claystone, and siltstone	Shallow alluvium, underlain by stratified sandstone, siltstone and claystone	Eolian sand and alluvial gravel with granite outcrops, underlain by conglomerate sandstone	Clay, sand, silt alluvium, underlain by fine to coarse grained sandstone, and siltstone

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(a) Chen and Associates, Inc. (1980)
(b) Getty Oil Company (1976)
(c) Atomic Energy Commission (1974)
(d) Dames and Moore (1975a)
(e) U.S. Nuclear Regulatory Commission (1979-)
(f) Dames and Moore (1979)
(g) U.S. Nuclear Regulatory Commission (1977a)
(h) Kaiser Engineers (1979)
(i) U.S. Nuclear Regulatory Commission (1977b)
(j) Exxon Company, U.S.A. (1973)
(k) Dames and Moore (1977)
(l) U.S. Nuclear Regulatory Commission (1977c)
(m) Kerr-McGee Nuclear Corp. (1977)
(n) U.S. Nuclear Regulatory Commission (1980a)
(o) Dames and Moore (1975b)
(p) U.S. Nuclear Regulatory Commission (1978)

KEY

NA--not available
ha--hectare
km--kilometer
sq mi--square mile
sec--second
h--hour
%--percent
PMP--Probable Maximum Precipitation
PMT--Probable Maximum Thunderstorm

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TABLE 6.3. Eolian Disruption Parameters for Mills in the Wyoming Basins

	Shirley Basin		Gas Hills			Powder River Basin				Others	
Parameters	Petrotomics(a)	Pathfinder(b)	UCC(c)	Pathfinder(d)	FAP(e)	Rocky Mt. Energy Co.(f)	Exxon(g)	United Nuclear(h)	Kerr-McGee(i)	Western Nuclear(j)	Minerals(k) Exploration
Historical Wind Data:											
Mean Velocity (m/sec)	4 (SW)	4 (SW)	NA	4 (WSW)	NA	6 (SW)	6 (SW)	6 (SW)	5 (SW)	6 (SW)	6 (SW)
Maximum Gust (m/sec)	36(1)	36(1)	36(1)	36(1)	36(1)	33 (SSW)	33 (SSW)	33 (SSW)	33 (SSW)	33 (SSW)	33 (SSW)
Angle Between Mean Wind Direction and Long Axis of Pond (degrees)	90	45	45	45	NA	0	90	0	NA	45	NA
Width of Tails (m) Pile Along Wind Direction (m)	915	A=305 B=150	760	760	NA	1500	790	2600	NA	1200	NA
Location of Dams in Relation to Pond	West	East	North and East	Northwest	NA	Northwest	Northwest	--	NA	Northwest	--
Storm Potential:											
Tornado Frequency (per yr)	NA	NA	0.00002	NA	NA	0.0003	NA	NA	0.0003	0.0008	NA
Tornado Velocity (m/sec)	NA	NA	97	NA	NA	97	NA	NA	97	97	NA

TABLE 6.3. (contd)

Parameters	Shirley Basin		Gas Hills			Powder River Basin				Others	
	Petrotomics(a)	Path-finder(b)	UCC(c)	Path-finder(d)	FAP(e)	Rocky Mt. Energy Co.(f)	Exxon(g)	United Nuclear(h)	Kerr-McGee(i)	Western Nuclear(j)	Mineral Exploration(k)
Soil Characteristics:(m)											
Slope Range (%)	3 to 8	3 to 8	4 to 20	4 to 20	0 to 15	0 to 15	5 to 12	4 to 14	4 to 14	NA	0 to 10
Surface Texture	Coarse	Coarse	Medium	Medium	Medium	Medium	Medium-Coarse	Fine-Medium	Fine-Medium	Medium-Coarse	Medium
Depth to Bedrock (cm)	>150	>150	50 to >150	5 to >150	50 to >150	80 to >150	50 to >150	50 to 100	50 to >100	25 to >150	>150
Depth to Water Table (cm)	>150	>150	>150	>150	>150	>150	>150	>150	>150	NA	>150
Permeability	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Slow	Slow	NA	Moderate
Soil Erodibility	Low-Medium	Low-Medium	Low-Medium	Low-Medium	Low-Medium	Low-Medium	Low-Medium	Medium	Medium	Low-Medium	Medium
Wind Erosion Potential	Medium-High	Medium-High	Medium	Medium	Medium	Low-Medium	Medium	Low-Medium	Low-Medium	Medium-High	Medium

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(a) Chen and Associates, Inc. (1980)
(b) Atomic Energy Commission (1974)
(c) Dames and Moore (1979)
(d) U.S. Nuclear Regulatory Commission (1977a)
(e) Kaiser Engineers, Inc. (1979)
(f) U.S. Nuclear Regulatory Commission (1977b)
(g) Exxon Company, U.S.A. (1973)
(h) U.S. Nuclear Regulatory Commission (1977c)
(i) Kerr-McGee Nuclear Corp. (1977)
(j) U.S. Nuclear Regulatory Commission (1980a)
(k) U.S. Nuclear Regulatory Commission (1978)
(l) U.S. Geological Survey (1970)
(m) Soil data not available from U.S. NRC Environmental Impact Statements were obtained from the Wyoming General Soil Map. 1977. Research Journal 117, University of Wyoming, Laramie, Wyoming and from County soil maps from the Wyoming Soil Conservation Service, Cheyenne, Wyoming.

KEY

Types of Ponds: A--above ground, with dikes
B--natural or excavated pits
C--lined cells or trenches

m--meter
sec--second
NA--not available
yr--year

TABLE 6.4. Seismic and Geothermal Disruption Parameters for Mill in the Wyoming Basins

	Shirley Basin		Gas Hills			Powder River Basin				Others	
Parameters	Petrotomics	Pathfinder	UCC	Pathfinder	FAP	Rocky Mt. Energy Co.	Exxon	TVA	Kerr-McGee	Western Nuclear	Minerals Exploration
Distance to (km):											
Nearest Earthquake (>V MM)[a]	56	56	30	34	38	77	72	70	56	NA	29
Active Fault[a]	19	19	12	11	6	64	45	40	45	5	5
Hydrothermal System[b] (>100 x 10^{18} J)	457	457	330	330	278	278	445	456	432	330	362
Igenoues System[b] (>10,000 x 10^{18} J)	457	457	330	330	278	278	445	456	432	330	362
Maximum Ground Acceleration	0.07[c]	0.03[d]	0.04[e]	0.05[f]	0.05[g]	NA	0.05[h]	NA	NA	NA	0.04[i]

(a) U.S. Geological Survey (1970)
(b) U.S. Geological Survey (1979)
(c) Chen and Associates, Inc. (1980)
(d) Atomic Energy Commission (1974)
(e) Dames and Moore (1979)
(f) U.S. Nuclear Regulatory Commission (1977a)
(g) Kaiser Engineers (1979)
(h) Exxon Company, U.S.A. (1973)
(i) U.S. Nuclear Regulatory Commission (1978)

KEY

km--kilometer
g--gravity (acceleration due to)
NA--not available

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7.0 COLORADO PLATEAU

The Colorado Plateau is a regional uplift of approximately 333,000 km^2 that roughly circles the Four-Corners area of Utah, Colorado, New Mexico, and Arizona (Figure 4.1). Historically, the region has been the nation's largest uranium producer. Numerous mines and mills are located in the Grants Mineral District of northeastern New Mexico as well as in the Paradox Basin of southeastern Utah and southwestern Colorado. This area has great potential for production capacity in the future (U.S. Department of Energy 1980).

Eroded plateaus and badlands characterize the terrain. Harsh winters and mild summers are typical of the semiarid climate. Between 20 to 40 cm (8 to 16 in.) of precipitation falls per year. Strong winds are common throughout the area, and wind and water erosion are the natural phenomena with the greatest disruptive potential in the Colorado Plateau. A slight chance of disruption from seismic activity and tornados exists.

7.1 REGIONAL CLIMATOLOGY AND METEOROLOGY

Annual evaporation greatly exceeds annual precipitation, giving the Colorado Plateau a semiarid climate. The region has cool summers and harsh winters, with wide fluctuations in daily and yearly temperatures. Gusty winds, thunderstorms, tornados, and freezing and thawing are climatic characteristics of the region that could disrupt uranium mill tailings piles.

Precipitation in the Colorado Plateau ranges between 20 to 40 cm/year (8 to 16 in.) with the greatest amount occurring in the late summer as convectional rain storms. Severe blizzards are common during the winter, usually appearing as dry frontal snow storms and containing little moisture. Annual pan evaporation in the region ranges between 150 to 250 cm (60 to 98 in.). Summer highs near 40°C and winter lows around -18°C are common. Mean annual freeze-free days range beween 120 to 150 (Argonne National Laboratory 1979).

Winds in the region are typically from the west-northwest and average between 2.5 to 4.5 m/sec throughout the year. Local gusts can range up to 30 m/sec. Tornados occasionally result from summer thunderstorms within the Colorado Plateau. Tornado frequency data collected for the region indicate that the mean annual incidence of tornados per 26,000 km^2 ranges between 0 to 2 (Nelson and Shepherd 1978).

7.2 REGIONAL HYDROLOGY

Surface water occurs in the Colorado River drainage basin, except for in the southeast corner of the Colorado Plateau. Tributaries to the basin include the Dolores River, San Miguel River, and San Juan River. Uranium-producing areas near Grants, New Mexico (in the southeastern region of the plateau), are drained by tributaries of the Rio Grande River.

Because of the Colorado Plateau's semi-arid climate, virtually all surface water is confined to major drainage basins and is fed by mountain snowmelt and springs. Surface runoff does not exceed 1.27 cm/year (0.5 in./year) anywhere in the region. Wide variations in river flow rates occur because rains in the region are irregular and often come as thunderstorms. This phenomenon has important implications in the assessment of mill tailings stabilization and will be evaluated on a site-specific basis.

Although uranium-producing areas of the Colorado Plateau are underlain by clastic sediments that may provide aquifers, low precipitation prevents recharge and limits ground water. Large aquifers occur within 300 km of the Four Corners area; however, a majority of the uranium-producing provinces do not fall within this radius. Current knowledge of hydrologic conditions beneath uranium-producing areas is incomplete. It is generally acknowledged that low precipitation and impermeable rocks limit ground-water accumulation and transmission (Cooley et al. 1969).

7.3 REGIONAL SOILS

Soils of the Colorado Plateau can be classified under one of three orders: Aridisols, Endisols, or Mollisols. Aridisols and Endisols dominate in uranium-producing regions. Aridisols cover much of northeastern Arizona and southeastern Utah; Endisols are generally restricted to western Colorado and northwestern New Mexico. Endisols also occur in river valleys and in less arid areas of the western Colorado Plateau. Mollisols occur primarily on the southern and western fringes of the Colorado Plateau in central Arizona and west-central Utah.

7.4 REGIONAL GEOLOGY AND GEOMORPHOLOGY

The Colorado Plateau is a regional physiographic and structural province characterized by high plateaus, sedimentary basins, uplifts, intrusives, and volcanic fields. Rocks ranging in age from Precambrian to Recent are represented in the region, with the most common outcrops being Paleozoic and Mesozoic sediments. Although local deformation occurred during the Laramid Orogeny (60 to 80 million years ago), the Colorado Plateau has remained relatively stable throughout much of geologic time.

Surface rocks are primarily Paleozoic and Mesozoic sandstone, limestone, and shales. Volcanic tuff of the Cenozoic age also occur in the Grants uranium belt as well as in the San Juan and Uinta Basins. In addition, Precambrian granitic and metamorphic basement rocks crop out in the Uncompahgre and Zuni uplifts and in the Grand Canyon. Tertiary intrusives are common in local mountain ranges (U.S. Department of Energy 1980).

During much of Paleozoic time the region was a marine basin undergoing deposition. Vertical displacement of crustal blocks in late Paleozoic time resulted in the ancestral Uncompahgre and Zuni uplifts. Regional uplift of the entire plateau during late Mesozoic and early Cenozoic times formed a number of local basins and uplifts. This uplift also halted regional deposition and started erosional processes that have carved the area into buttes, mesas, plateaus, and canyon lands.

7.5 REGIONAL SEISMICITY AND GEOTHERMAL POTENTIAL

As a regional unit, the Colorado Plateau has experienced relatively few earthquakes during recorded history. Most seismic activity occurs along regional boundaries rather than within the physiographic province.

Earthquakes greater than intensity V (MM) have been recorded southwest of Albuquerque, New Mexico, in a line roughly parallel to the southeast border of the Colorado Plateau. The eastern edge of the plateau has also experienced seismic activity that is believed to be related to faults along the San Juan Basin (Argonne National Laboratory 1979). Boundaries of the Colorado Plateau in Utah and Arizona have experienced earthquakes greater than intensity V(MM). Areas considered to have high seismicity potential are restricted to extreme northwest portions of the Colorado Plateau and are far removed from uranium-producing centers (Coffman and Von Hake 1973).

Geothermal potential is restricted to fringes of the plateau. Significant subsurface igneous systems occur near Flagstaff, Arizona, and Los Alamos, New Mexico. Surface hot springs are associated with the Los Alamos geothermal activity (U.S.G.S. 1979).

7.6 MILL SITE CHARACTERISTICS

Thirteen operating mills are located in the Colorado Plateau. Five mills are found in the Grants mineral district of northeastern New Mexico, and other mills are situated in southwestern Colorado and southeastern Utah. Together these mills process about 32,800 MT/day (36,100 tpd) of uranium ore. This region is the largest producer of uranium oxide. Important physical characteristics of mills in this region are summarized in Table 7.1.

7.6.1 Uravan Mill (Union Carbide Corp.)

The Uravan Mill is located in western Colorado, 80 km (50 miles) south of Grand Junction, in an area of rugged canyons and mesas. Vanadium is the major mill product; however, yellowcake is also produced by using a hot, highly oxidizing, two-stage acid leach. Uranium mill tailings are currently retained in two unlined disposal areas located in a bench along the San Miguel River and the Hieroglyphics Canyon. The heights of the tailings pond retention dams are 43 m (140 ft) and 32 m (105 ft), respectively. Overall slopes for the embankments range from 1.5H:1V to 2.5H:1V. The pond occupies approximately 32 ha (80 acres). Union Carbide has proposed to build a new tailings area by 1983 (Geotechnical Engineers, Inc. 1980).

7.6.2 Lisbon Mill (Rio Algom Co.)

The Lisbon Valley Mine/Mill complex is located about 48 km (30 miles) southeast of Moab, Utah, in a mountainous area. Alkaline-leach methods are used to process about 640 MT/day (700 tpd) of ore. After precipitation of sodium diuranate from the pregnant liquor, the precipitate is redissolved with sulfuric acid. The uranium values in the acid are then reprecipitated with anhydrous ammonia to form ammonium diuranate. After drying and calcining, the yellowcake product is formed. An earth-fill, clay-core dam retention system serves as a storage system for radioactive wastes. The dam is erected across a natural basin. It has a crest length of 440 m (1450 ft) and was originally 14 m (45 ft) high. Plans are being generated to add an additional 8 km (25 ft) to the top. The slope ratios are 2.5H:1V on the downstream side and 2H:1V on the upstream side. At the cessation of operation, the pile will be graded, covered with earth and topsoil, and seeded (U.S. Nuclear Regulatory Commission 1976).

7.6.3 Moab Mill (Atlas Minerals Corp.)

The Moab Mill is located in a mountainous region about 5 km (3 miles) northwest of the city of Moab, Utah. The mill originally used acid leach, but the process was changed to alkaline leach (using the same resin-in-pulp equipment). In 1968, a new acid-leach, solvent-extraction process circuit was added, which recovers 550 MT/day (600 tpd) of uranium ore. The alkaline-leach circuit recovers 540 MT/d (590 tpd) of high lime uranium ore. Vanadium also is recovered. A tailings pond impounds both liquid and solid wastes. The tailings impoundment is enclosed by four embankment walls composed primarily of tailings. Additional tailings dikes will probably have to be built. After a two-year, post-operational drying period, the pond will be shaped and contoured with final slopes no greater than 10H:3V. The tailings will be capped with clay and overlain with silty fine sand, and 0.3 m (1 ft) of gravel or topsoil. After covering, the area will be revegetated (U.S. Nuclear Regulatory Commission 1979b).

7.6.4 White Mesa Mill (Energy Fuels Nuclear, Inc.)

The White Mesa Mill is located about 8 km (5 miles) south of Blanding, Utah, on a nearly flat peninsula platform that tilts slightly to the southeast. The mill began operations in 1980, using acid-leach, solvent-extraction methods to process 1800 MT/day (2000 tpd) of ore and to yield both vanadium and uranium products.

A six-cell tailings impoundment system occupies about 142 ha (350 acres) of the site. The tailings cells are constructed by excavating the bottom of a natural depression and placing a series of retention dikes made of compacted soil across the excavated area to form the downstream sides of each cell. The dams have a maximum height of 13 m (42 ft), a crest of 6 m (20 ft), and slopes no greater than 3H:1V. The final exterior slope of the last embankment will have a slope of 6H:1V.

TABLE 7.1. Physical Characteristics of Mills in the Colorado Plateau

Mill Characteristics	Rio Algom[a]	Atlas[b,c]	Plateau Resources[d]	Energy Fuels Nuclear[e,f]	UCC[g] Uravan	Pioneer[h] Uravan	Sohio[i]	United Nuclear[j]	Anaconda[k,l]	Kerr-McGee[m]	Gulf Mineral Resources[n]	Bokum[o,p]	Homestake[q]
Location	38°16'N 109°17'W	38°36'N 109°36'W	37°43'N 110°41'W	37°30'N 109°30'W	38°22'N 108°45'W	38°2'N 108°20'W	35°10'N 107°20'W	35°35'N 108°35'W	35°15'N 107°57'W	35°23'N 107°50'W	107°39'N 35°27'W	107°17'N 35°19'W	35°15'N 107°52'W
Type of Pond	A	A	A	A (six cell)	A	C	A	A	A,C	A	C	C	A
Tailings Area (ha)	14	47	28	135	32	60	25	80	A = 110	100	90	60	60
Tailings Dimensions (m)[q]	1100 x 730	980 x 730	430 x 670	1525 x 670	NA	790 x 790	518 x 760	300 x 180	A = 610 x 1220 C = 1200 x 1800	1200 x 1800	NA	1070 x 760	600 x 1200
Embankment (Pond Type A) Material	Earth fill, clay-core	Tailings, sand, gravel	Earth, sand, gravel	Native soils	NA	---	Earthen	Native clay and coarse compacted tailings	Compacted clay	Coarse tailings and slimes	---	---	Natural soils and coarse tailings
Slope	2.5H:1V	1.5H:1V	2H:1V	6H:1V	2H:1V	---	NA	3H:1V	1.5H:1V	NA	---	---	1.5H:1V
Height (m)	21	23	36	8 to 13	32 to 43	---	30	21	NA	30	---	---	24
Site Elevation (MSL--m)[r]	2165	1220	1460	1710	NA	1730	2160	2130	2010	2130	2200	2010	2010
Leach Process	Alkaline	Alkaline and acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Alkaline
Ore Process Rate MT/day[s]	640	1100	680	1800	1200	900	1500	3600	6200	6300	3800	2000	3100

(a) U.S. Nuclear Regulatory Commission (1976)
(b) U.S. Nuclear Regulatory Commission (1979b)
(c) Atlas Corporation (1975)(b)
(d) U.S. Nuclear Regulatory Commission (1979c)
(e) U.S. Nuclear Regulatory Commission (1979d)
(f) D'Appolonia (1979)
(g) Geotechnical Engineers, Inc (1980)
(h) Pioneer Nuclear, Inc. (1979)
(i) Sohio (1980)
(j) United Nuclear Corp. (1975)
(k) U.S. Atomic Energy Commission (1969)
(l) Dames and Moore (1981)
(m) Kerr-McGee Nuclear Corp. (1981)
(n) Earth Science Associates (1980)
(o) U.S. Nuclear Regulatory Commission (1980c)
(p) Civil System, Inc. (1979)
(q) Hydro-Engineering (1981)
(r) Topographic maps shown in Appendix
(s) U.S. Nuclear Regulatory Commission (1980b)

KEY

NA-- not available
Type of pond: A--above ground, with trenches
B--natural or excavated pits
C--lined cells or trenches
Na--hectare
m--meter
H:V--horizontal:vertical
MSL--mean sea level
MT--metric tonne

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As the first cell is filled and reclaimed, the next cell downstream is filled with tailings, while a third cell is constructed and lined with a PVC liner. Reclamation of each cell includes a 0.6-m (2-ft) clay cap with 4 m (12 ft) of local soils. Reclaimed slopes will be riprapped; slopes will be no steeper than 6H:1V (U.S. Nuclear Regulatory Commission 1979d).

7.6.5 Shootering Canyon Mill (Plateau Resources Limited)

The proposed Shootering Canyon site is to be located about 8 km (5 miles) south of Mt. Ellsworth in southeastern Utah. Bluffs and mesas are typical of the landscape in the proposed mill vicinity. The mill is designed to process ore at a rate of 680 MT/day (750 tpd) using conventional acid-leach, solvent-extraction methods of recovery.

The tailings pond is an 11-ha (28-acre) impoundment located in a natural basin. The impoundment is closed by an engineering embankment 36 m high by 460 m long (118 ft high by 1500 ft long). The floor and the sides of the basin will be lined with a compacted clay-silt-sand material. A dewatering system will be installed in the lower portion of the tailings impoundment. The proposed reclamation program calls for 3 m (9 ft) of compacted clay cover and 0.3 m (1 ft) of sand, gravel, and cobbles (riprap). The riprap will also cover the downstream face of the dam with a 2H:1V slope. Sediment-laden runoff from the drainage basin above the dam will pond over the cover and evaporate, leaving additional sediment to protect the cover. After reclamation, two spillways will be constructed. Both spillways will have crest elevations 1 m (3 ft) above the cap of the tailings pond (U.S. Nuclear Regulatory Commission 1979c).

7.6.6 San Miguel Project (Pioneer Uravan, Inc.)

The proposed San Miguel Mill is to be located in the Disappointment Valley, 6 km (4 miles) east of Slick Rock, Colorado. The ore will be treated using conventional sulfuric acid-leach, solvent-extraction methods. The mill tailings will be handled through a dry-disposal, continuous reclamation method. The tailings disposal system will consist of a series of 10 north-south strip cuts, 76 m (250 ft) wide and 760 m (2500 ft) long. Each pit will have a depth of 9 m (30 ft). The total tailings area will occupy 70 ha (172 acres). Backfilling, grading, and revegetation of the reclamation cover probably will be accomplished throughout the life of the project (Pioneer Nuclear, Inc. 1979).

7.6.7 Bluewater Mill (Anaconda Co.)

Anaconda's Bluewater uranium mill is located in the San Jose River Valley Belt, about 16 km (10 miles) northwest of Grants, New Mexico. Mesas surround the mill to the north, east, and south. The mill uses an acid-leach, solvent-extraction process; however, magnesium oxide is used as the precipitation agent rather than ammonia.

Tailings are currently transported via a slurry pipeline into a natural basin to the north of the plant area. The tailings pond has retention dams on all sides. All dams have a 4 to 9-m (12 to 30-ft) crest and a 1.5H:1V to 2H:1V slope. Riprap lines part of the north-facing dam. The maximum height of the tailings pile is 18 m (60 ft) (Anaconda Company 1969).

A new below-grade disposal system is being planned for use in 1984. The proposed system will consist of a series of parallel trenches. As each trench is filled with tailings, an adjacent trench will be excavated and the excavated material will be used as backfill for the previous trench. The trenches will be 90 m (300 ft) wide, up to 2280 m (7500 ft) long, and 15 to 20 m (50 to 70 ft) deep. Reclamation cover will vary from 3 to 13 m (10 to 40 ft) in depth. Final slopes will be no greater than 10H:1V (Dames and Moore 1981).

7.6.8 Church Rock (United Nuclear Corp.)

The Church Rock Mill, 32 km (20 miles) northeast oF Gallup, New Mexico, is characterized by rolling hills. The mill, which processes 3640 MT/day (4000 tpd) of ore through an acid-leach process, opened in 1977.

The tailings pond is formed by a dam built from native clays and compacted coarse tailings. The dam will ultimately be approximately 21 m (70 ft) high and 3 km (2 miles) long, with a total tailings area of 83 ha (204 acres) (United Nuclear Corp. 1975).

7.6.9 L-Bar Mill (Sohio Petroleum Co.)

The L-Bar Mill site is located about 29 km (18 miles) north of Laguna, New Mexico, and is characterized by flat terrain. The mill began operation in 1976 with a capacity of 1500 MT/day (1650 tpd) of ore. The mill uses a sulfuric acid-leach, solvent-extraction circuit, followed by precipitation with ammonia, to process the uranium. Tailings are transported as a slurry from the mill to a 65-ha (160-acre) tailings pond. The pond is an above-ground impoundment built of natural materials, with an engineered starter dam (Sohio Western Mining Company 1980).

7.6.10 Mt. Taylor Project (Gulf Mineral Resources)

The Mt. Taylor Uranium Mill Project is located in northwestern New Mexico, approximately 48 km (30 miles) northeast of Grants. The proposed mill, scheduled to begin operations in 1983, will process 3800 MT/day (4180 tpd) of ore through acid-leach methods. A 10-km (6-mile) pipeline will transport tailings to an impoundment located in La Polvadera Canyon, a natural canyon bordered on three sides by high bluffs providing protection from wind and storm damage. A series of trenches will be excavated into bedrock units of predominantly shales and silt stones. Berms will be constructed at intervals along the trench bottom to promote settling of slimes. The trench will be filled with tailings to 5 ft below existing ground level. Reclamation of the tailings burial will begin after a trench is filled and covered with mine spoil. The area will be graded and covered with topsoil. The reclaimed trench area will have a 15-m (50-ft) cover and will be contoured to about 8H:1V slopes (Earth Science Associates 1980).

7.6.11 Marquez Project (Bokum Resources)

The Marquez Project Mill, scheduled to begin operations in the near future, is about 5 km (3 miles) northeast of Marquez, New Mexico. The mill site is located on top of Mesa Marquez; however, the proposed tailings disposal area is located below the mesa, in a valley. The tailings will be deposited in six trenches, excavated sequentially. Each trench will be filled to a level below the lowest point of the adjacent ground surface, and on reclamation, covered with at least 3 m (10 ft) of soil. After reclamation, the pond will have a gentle, broadly convex surface. Slopes near trench areas will be about 10H:1V and slopes near non-trench areas will be 8H:1V. The toe of the reclaimed slopes is to be riprapped at selected locations (U.S. Nuclear Regulatory Commission 1980c).

7.6.12 Ambrosia Lake Mill (Kerr-McGee Nuclear Corp.)

The Ambrosia Lake Mill is located about 40 km (25 miles) north of Grants, New Mexico. The mill extracts uranium and molybdenum through a conventional sulfuric acid-leach, solvent-extraction process and has a rated capacity of 6350 MT/day (6980 tpd). Tailings are deposited into a system of 21 tailings and decantation ponds covering 140 ha (350 acres). The pile will reach a maximum height of 30 m (100 ft). After operations have ceased, the tailings area will be contoured to a slope of 5H:1V and covered with clay or dirt. Some areas will be riprapped with locally available stone.

7.6.13 Homestake Mill (Homestake Mining Company)

Homestake Mill is located about 16 km (10 miles) northwest of Grants, New Mexico. It currently processes about 2300 MT/day (2530 tpd) of uranium ore, along with an 8% vanadium by-product. The mill uses an alkaline leach process after fine-grinding the ore. Tailings are discharged via a pipeline into an above-grade impoundment covering an area of 105 ha (260 acres). In April, 1980, the tailings material reached a height of 26 m (85 ft) (U.S. Nuclear Regulatory Commission 1980b).

7.7 PRECIPITATION AND POTENTIAL FLOOD STRESSES

Flood parameters for this region are summarized in Table 7.2. Mean annual precipitation ranges from 18 to 36 cm (7 to 14 in.). However, data indicate that all sites are susceptible to flash flooding. Thus, a most important factor is the proximity of a site to a stream. The Moab, Shootering Canyon, and Marquez sites are the most vulnerable. Reported maximum values for stream flow for the Moab site are 2190 m^3/sec (78,300 cfs) with a velocity of 3 to 5 m/sec (10 to 15 fps).

7.8 EOLIAN DISRUPTION POTENTIAL

The sites are characterized by moderate winds. Extreme wind velocities range from 23 to 36 m/sec (58 to 90 mph) for the sites studied. Tornado probabilities are very low. Eolian disruption parameters are summarized in Table 7.3.

7.9 SEISMIC AND GEOTHERMAL DISRUPTION POTENTIAL

Volcanic activity poses a potential hazard along the borders of this region. The Mt. Taylor, Bluewater, Marquez, and L-Bar sites are less than 160 km (100 miles) from an igneous system greater than 10,000 x 10^{18} J. Seismic risks are also relatively high; for example, maximum ground acceleration for the Pioneer Uravan site was reported at 0.2 g (see Table 7.4).

TABLE 7.2. Flooding Parameters for Mills in the Colorado Plateau

Parameters	Rio Algom[a]	Atlas[b,c]	Plateau Resources[d]	Energy Fuels Nuclear[e,f]	UCC Uravan[g]	Pioneer Uravan[h]	Sohio[i]	United Nuclear[j]	Anaconda[k]	Kerr-McGee[l]	Gulf Mineral Resources[m]	Bokum[n,o]	Homestake[p]
Nearest Stream	W. Coyote Wash	Moab Canyon Wash	Shootering Creek	Westwater Creek	San Miguel River	Nicholas Wash	Unnamed	Pipeline Canyon	San Mateo Creek	Arroyo Del Puerto	Unnamed	Arroyo Hondo	San Mateo Creek
Drainage Area for Stream (km^2)	NA	20	94	69	NA	20	NA	48	NA	135	NA	2.8	NA
Distance to Stream (m)(q)	1600	0	150	460	150	305	0	610	4000	0	60	0	60
Stream Elevation (m)(q)	2043	1220	1280	1670 to 1680	1525	1710 to 1730	1920	2160	2010	2130	2200	2010	2010
Site Elevation (m)	2040	1220	1460	1710	1590	1730	1920	2150	2010	2130	2170	2010	2010
Elevation Difference (m)	0	0	190	30 to 100	65	0 to 10	0	10	0	0	30	0	0
Stream Flow:													
Mean	NA	Intermittent	Intermittent	Intermittent	NA	Intermittent	Intermittent	Intermittent	NA	NA	NA	Intermittent	NA
Maximum (m^3/sec)	NA	46	NA	NA	NA	500	1500	40	NA	NA	NA	NA	NA
Proximity to Gaging Station (km)	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	48	NA	NA
Surface Runoff:													
Mean Annual (cm)	NA	NA	NA	1.3	NA	NA	NA	NA	NA	NA	0.2 to 13	NA	NA
Maximum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Slope of Surrounding Area (%)(r)	NA	1 to 3 (ESE)	40 to 80	1 to 5 (SSW)	0 to 30	0 to 15 (SSW)	0 to 30	NA	1 to 5	NA	10 to 13	1 to 9	1 to 5
Vegetation Density	Sparse	Sparse	Sparse	Sparse	NA	Sparse	Sparse	Sparse	NA	NA	Sparse	NA	Sparse
Vegetation Type	Grasses, weeds, and sagebrush	Sagebrush	Grasses and brush	Grasses, juniper, and sagebrush	NA	Grasses, shrubs, and juniper	Grasses, sagebrush, and juniper	Grasses, sagebrush, and juniper	NA	Grasses	Grasses, cactus, and shrubs	Cactus, grasses, and juniper	Grasses
Precipitation:													
Mean Annual (cm)	22	22	18	30	26	22	20	33	NA	22	22	25	25
Maximum Recorded (cm)	NA	40	NA	NA	32	4 in 24 h	NA	NA	NA	33	33	NA	NA
Snowfall (cm)	NA	152	102	NA	NA	127	27	NA	NA	NA	66	30	NA
Period of Record (yr)	53	60	1	30	1 to 4	30	30	20	NA	24	35	NA	NA
Evaporation:													
Mean Annual (cm)	152	152	NA	90	NA	150	NA	127	NA	NA	144	127	152
Period of Record (yr)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PMP	19 in 1 hr (site)	13 in 6 h (site)	NA	19 in 1 h (site)	NA	19 in 1 h (site)	50 in 6 hr (site)	50 in 6 h (site)	NA	NA	NA	40 in 6 hr (site)	NA
Tailings Pond:													
Drainage Area (ha)	240[s]	NA	NA	NA	20	590	NA	NA	NA	NA	20(%)	NA	NA
Underlying Geology	Stiff clay and sand, underlain by sandstone, siltstone, and minor shales.	Deep alluvial sands and gravels, underlain by conglomerate sandstones and shales.	Shallow talus and sand, underlain by weakly cemented sandstone and siltstone.	Eolian sands, underlain by sandstone	Shallow eolian clays and fine sands, underlain by shales, siltstone, sandstone, and conglomerate sandstone.	Thin alluvium, underlain by calcerous shale, sandstone, and claystone.	Silty clay alluvium, underlain by clay stone, and sandstone bedrock.	Alluvial sands and silt, underlain by moderately weathered sandstone.	Alluvial soils, underlain by basaltic rock or siltstone, mudstone, and some conglomerate interbeds.	Alluvial soils, underlain by sandstone and shales.	Sands and gravels, underlain by poorly cemented sandstone, siltstone, and shale.	Alluvial and eolian deposits to 9 m, underlain by impervious shale.	Alluvial deposits, underlain by shales, siltstone, with fine-grained interbeds.
Runoff Potential	Medium		Moderately low	Low	Medium to high		Medium to high	Medium	Medium	Medium	Medium	Medium	Low to high

KEY

NA--not available
km--kilometer
m--meter
sec--second
cm--centimeter
h--hour
PMP--Probable Maximum Precipitation

(a) U.S. Nuclear Regulatory Commission (1976)
(b) U.S. Nuclear Regulatory Commission (1979b)
(c) Atlas Corporation (1975)
(d) U.S. Nuclear Regulatory Commission (1979c)
(e) U.S. Nuclear Regulatory Commission (1979d)
(f) D'Applonia (1979)
(g) Geotechnical Engineers, Inc. (1980)
(h) Pioneer Nuclear, Inc. (1979)
(i) Sohio Western Mining Company (1980)
(j) United Nuclear Corp. (1975)
(k) Anaconda Co. (1969)
(l) Kerr-McGee Nuclear Corp. (1981)
(m) Earth Science Associates (1980)
(n) U.S. Nuclear Regulatory Commission (1980c)
(o) Civil System, Inc. (1979)
(p) Hydro-Engineering (1981)
(q) Topographic maps shown in Appendix
(r) Personal communication from Gordon Swanby to John Lineham in USNRC Docket 40-3453 (1980)
(s) Dames and Moore (1973)

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TABLE 7.3. Eolian Disruption Parameters for Mills in the Colorado Plateau

Parameters	Rio Algom[a]	Atlas[b,c]	Plateau Resources[d]	Energy Fuels Nuclear[e,f]	UCC Uravan[g]	Pioneer Uravan[h]	Sohio[i]	United Nuclear[j]	Anaconda[k]	Kerr-McGee	Gulf Mineral Resources[l]	Bokum[m,n]	Homestake[o]
Historic Wind Data (m/sec):													
Mean Velocity	NA	3 (WSW)	NA	4 (S)	2 (SE)	3 (ENE, SSW)	4 (ENE)	NA	NA	2 (NNW)	NA	NA	NA
Maximum Gust	20	NA	NA	NA	NA	NA	23 (W)	NA	NA	35 (SW)	35 (SW)	36 (SW)	NA
Angle Between Mean Wind Direction and Long Axis of Pond (degrees)	NA	90	NA	0	90	30	0	NA	NA	45	NA	NA	NA
Width of Tails Pile Along Wind Direction (m)	NA	1500	NA	915	2000	915	1200	NA	NA	1250	NA	610	NA
Location of Dams in Relation to Ponds	NA	All sides except west	NA	NA	NA	--	West Northeast	NA	Southwest South, East North	NA	NA	NA	NA
Tornado Frequency	NA	NA	0.00032/yr	NA	NA	0.00015/yr	NA	NA	NA	NA	0.00016/yr	NA	NA
Soil Characteristics:[p]													
Slope Range (%)	NA	NA	4 to 30	2 to 10	NA	NA	5 to 50	3 to 25	0 to 10	0 to 3	1 to 9	1 to 75	1 to 9
Surface Texture	Fine-Medium	NA	Coarse	Coarse	Fine-Coarse	NA	Coarse	Medium-Coarse	Medium	Fine-Medium	Medium	Medium-Coarse	Fine-Coarse
Depth to Bedrock	140	NA	50 to 150	170	0 to 90	NA	10 to 50	10 to 50	25 to 100	150	50 to 200	15 to 152	150
Depth to Watertable	760	215	6300	1500 to 3000	NA	NA	NA	NA	NA	NA			
Permeability	Slow	NA	NA	Moderate	NA	NA	Rapid	Slow-Rapid	Slow	Slow-Moderate	Slow	Slow-Rapid	Slow-Moderate
Soil Erodibility	NA	NA	NA	Medium	NA	NA	NA	NA	NA	NA	High	NA	NA
Wind Erosion Potential	Medium	NA	High	Medium	Medium-High	NA	Medium-High	Medium	Medium	Medium	Medium	Medium	Low-High

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(a) U.S. Nuclear Regulatory Commission (1976)
(b) U.S. Nuclear Regulatory Commission (1979b)
(c) Atlas Corporation (1975)
(d) U.S. Nuclear Regulatory Commission (1979c)
(e) U.S. Nuclear Regulatory Commission (1979d)
(f) D'Appolonia (1979)
(g) Geotechnical Engineers, Inc. (1980)
(h) Pioneer Nuclear, Inc. (1979)
(i) Sohio (1980)
(j) United Nuclear Corp. (1975)
(k) U.S. Atomic Energy Commission (1969)
(l) Earth Science Associates (1980)
(m) U.S. Nuclear Regulatory Commission (1980c)
(n) Civil System, Inc. (1979)
(o) Dames and Moore, (1977)
(p) Soil data not available from U.S. NRC Environmental Impact Statements were obtained from:
- County General Soil Maps, Utah, Colorado, New Mexico Soil Conservation Services
- Soils of New Mexico Map, New Mexico State University, Research Report 285

KEY

m--meter
sec--second
yr--year
h--hour

TABLE 7.4. Seismic and Geothermal Disruption Parameters for Mills in the Colorado Plateau

Parameters	Rio Algom	Atlas	Plateau Resources	White Mesa	UCC Uravan	Pioneer Uravan	Sohio	United Nuclear	Anaconda	Kerr-McGee	Gulf Mineral Resources	Bokum	Homestake
Distance to (km):													
Nearest Earthquake(a)	160	140	110	190	110	50	70	80	90	60	60	90	85
Active Fault(a)	40	40	50	70	0	20	25	50	10	40	60	20	15
Fault Length(a)	70	70	150	50	50	50	140	70	70	70	70	70	70
Hydrothermal(b) System (10 to 1000 x 10^{18}J)	290	280	220	300	320	320	96	160	130	130	120	96	130
Igneous System(b) (1000 to 10,000 x 10^{18}J)	370	390	260	290	320	320	96	160	130	130	120	96	130
Maximum Ground Acceration (g's)	0.05(c)	0.05(d)	NA	0.4(e)	0.12(f)	0.2(g)	0.06(h)	0.1(i)	0.1(j)	NA	0.1(k)	0.1(l)	NA

(a) U.S. Geological Survey (1970)
(b) U.S. Geological Survey (1970)
(c) Dames and Moore (1973)
(d) Atlas Corporation (1975)
(e) D'Applonia (1979)
(f) Geotechnical Engineers, Inc. (1980)
(g) Pioneer Nuclear, Inc. (1979)
(h) Sohio (1980)
(i) United Nuclear Corp. (1975)
(j) Dames and Moore 1981
(k) Earth Science Associates (1980)
(l) Civil System, Inc. (1979)

KEY

km--kilometer
g--gravity (due to acceleration)

8.0 TEXAS GULF COAST

Uranium-producing centers in Texas are located along a mineralized belt 160 km (100 miles) inland from Corpus Cristi that roughly parallels the coastline (see Figure 4.1). Although numerous uranium properties have been developed in the area, only two conventional mills are currently active. They are located in Karnes and Wilson Counties within the San Antonio River drainage.

The regional climate is subtropical to semiarid with modest temperatures and precipitation. The region is tectonically stable but contains substantial amounts of geothermal and geopressured energy. Environmental factors that have the greatest potential for disrupting uranium mill tailings are tropical storms, tornados, and floods.

8.1 REGIONAL CLIMATOLOGY AND METEOROLOGY

Regions adjacent to the Gulf of Mexico along the Texas Gulf Coast have a humid subtropical climate, whereas regions further inland are semiarid. Rainfall and temperatures are moderate, rarely reaching extremes. Sudden tropical storms are the greatest climatic danger to uranium tailings piles.

Precipitation in the region averages from 35 to 115 cm/year (14 to 45 in.) and is strongly influenced by tropical storms during the summer and fall. Annual evaporation ranges from 165 to 215 cm (65 to 85 in.).

The annual temperature of the Texas Gulf Coast averages 21°C, with extremes ranging from 0°C to 38°C. Seasons are distinct with a short transition between summer and winter. The growing season can last over 300 days.

Winds along the Texas Gulf Coast tend to be east to southeasterly and average 5 m/sec (12 mph). Maximum wind gusts can reach 50 m/sec (120 mph). Tornados and hurricanes are common and can be damaging (Argonne National Laboratory 1979).

8.2 REGIONAL HYDROLOGY

Surface water in uranium-producing areas of the Texas Gulf Coast is dominated by the San Antonio and Nueces Rivers. Several other river drainages and numerous streams cross areas for potential future uranium production.

One currently producing uranium mill is located in Karnes County near the community of Falls City, Texas, along the San Antonio River Valley. Historical data taken near Falls City over the last 53 years by the U.S.G.S. indicate an average discharge of 11 m^3/sec (383 cfs). Extremes during the period range from 0.4 to 1300 m^3/sec (15 to 47,400 cfs). Data collected on the Nueces River near the city of Three Rivers, Texas, over a 63-year period indicate an average discharge of 24 m^3/sec (862 cfs). Discharge extremes range from no flow to 3950 m^3/sec (141,000 cfs) (U.S. Geological Survey 1978).

Clastic sediments in the Texas Gulf Coast region result in conditions favorable for ground-water accumulation. Large sections of Karnes County are underlain by the Wilcox-Carrizo aquifer, which has a measured transmissivity averaging 620 m^2/day. In addition, large capacity wells in the aquifer discharge nearly 200 l/sec (Argonne National Laboratory 1979).

8.3 REGIONAL SOILS

Soils of the Texas Gulf Coast uranium-producing regions are predominantly alkaline Alfisols composed of a sandy loam surface layer overlying an argillaceous or sandy loam horizon. In some of these soils, the clay horizon rests on a calcareous layer. In Wilson and Karnes Counties the soils tend to be well drained with slow permeability. Runoff is also slow, although available water capacity is medium (Taylor 1977).

8.4 REGIONAL GEOLOGY AND GEOMORPHOLOGY

Regional geology of the Texas coastal plain is characterized by both marine and nonmarine Tertiary sediments that gently dip into the gulf coast geosyncline. In the coastal hinterland these stratigraphic units unconventionally overlie older sediments, and metamorphic and igneous rocks.

Lithologic units of the area consist of sandstone, mudstone, and claystone. Vertical and horizontal facies changes between marine and nonmarine deposits indicate an undulating coastline during deposition. Late Tertiary volcanics occur over much of the area and are thought to be the source of uranium deposits that occur in underlying sandstone (Campbell 1977).

The Texas coastal plain has low relief with elevation typically less than 160 m (520 ft). Wind-transported sand and silt form a gently rolling landscape with sparse vegetation. Further from the coast, sand dune areas grade into dissected prairie lands and low woodlands.

8.5 REGIONAL SEISMICITY AND GEOTHERMAL POTENTIAL

All of southern Texas, including the Gulf Coast region, has been seismically stable throughout recorded history. No earthquakes greater than intensity V (MM) have been recorded (Coffman and Von Hake 1973). Fault systems west of the uranium-producing areas have remained inactive in recent times.

Although no major igneous systems are located along the Texas Gulf Coast, the region has significant amounts of geothermal and geopressured energy. Studies by the U.S.G.S. estimate 107,000 x 10^{18} J of thermal energy are contained in pore waters of sandstone and shale to a depth of 6800 m (22,000 ft) in the northern gulf of the Mexico Basin (U.S. Geological Survey 1979). In addition, much of this geothermal water is saturated with methane gas and is under pressure.

8.6 MILL SITE CHARACTERISTICS

Two mills are located on the Texas Gulf Coast: the Conquista Mill (Conoco Oil/Pioneer Nuclear) and the Panna Maria Mill (Chevron Resources Co.). Together these mills process about 3240 MT/day (3560 tpd) of ore. Few data were available on the physical characteristics of these mills.

8.6.1 Conquista Mill (Conoco Oil/Pioneer Nuclear)

The Conquista Mill is located near Fall City, Texas, about 48 km (30 miles) southeast of San Antonio. The mill began operation in 1972. It produced about 540 MT/day (590 tpd) of ore, but is temporarily shut down, according to the Texas Health Department. A separate impoundment, underlain by bentonitic clay and natural shale, collected plant tailings. Dikes surround the impoundment on three sides, and the remaining side is keyed into the side of a hill. The embankments are constructed of clay and earthen materials (Campbell 1977).

8.6.2 Panna Maria Mill (Chevron Resources Co.)

The Panna Maria Mill is located about 260 km (160 miles) northwest of Corpus Christi, in Panna Maria, Texas. The mill processes about 2700 MT/day of ore (2970 tpd) and began operations in January 1970. Tailings are deposited in an above-ground impoundment.

8.7 PRECIPITATION AND POTENTIAL FLOOD STRESSES

Few site-specific data are available for the two mills located on the Texas Gulf Coast. Precipitation and flood data are based on regional information. Available flood data for mills are summarized in Table 8.1. This area has the greatest likelihood of receiving extreme precipitation caused by hurricane-related storms. The Texas Gulf Coast area has experienced 6 cm (2.5 in.) or more of rain in an hour. The effect of these storms is minimized by the natural vegetative cover and by the gentle slopes characterizing the mill regions. However, over the 1000-year period, a drought can be expected, so the vegetative protection may not be dependable. Water erosion is compounded by the alkaline clay soil of this region, which swells when wet. The swelling closes cracks in the ground, sometimes throwing fences, trees, and telephone poles out of line. When the ground drys, wide cracks that are subject to wind erosion form. Succeeding rains fill the cracks that swell from the wetting of subsoil, and the ground again becomes irregularly heaved (Hunt 1974).

8.8 EOLIAN DISRUPTION POTENTIAL

In determining wind erosion, the most important site characteristic is the direction and force of prevailing winds. Available data on soil characteristics are give in Table 8.2. Based on site data from an in situ facility nearby, wind speed is averaged at 4.2 m/sec (10 mph) from the south-southeast, with maximum gusts recorded of 32 m/sec (80 mph) from the north-northeast.

TABLE 8.1. Flooding Parameters for Mills on the Texas Gulf Coast[a]

Surface Runoff (cm/yr)	
Mean Annual	2 to 5
Maximum	8 to 5
Vegetation Density	Moderate
Vegetation Type	Grasses and brush
Precipitation (cm):	
Mean	70
Maximum Recorded	18 in 24 h
Snowfall	3
Mean Annual Evaporation	80
Soil Characteristics	
Runoff Potential	Low to Moderately Low

(a) Camp, Dressor and McGee, Inc. (1981)

TABLE 8.2. Soil Characteristics for Mills on the Texas Gulf Coast[a]

	Conquista Mill	Panna Maria Mill
Soil Characteristics:		
Slope Range (%)	0 to 8	0 to 5
Surface Texture	Fine	Fine to Medium
Depth to Bedrock (cm)	75 to 150	75 to 150
Depth to Water Table (in.)	NA	NA
Permeability	Slow	Slow to Moderate
Soil Erodability	NA	NA
Wind Erosion Potential	Medium	Medium

(a) Soil information for the mills was obtained from
- Soil maps for mill sites in Karnes County, Texas
  Soil Conservation Service, Austin, Texas

Tornados also occur more frequently and with high intensities because of the area altitude and humidity (Nelson and Shepherd 1978). The sites are also susceptible to hurricane winds of high intensity and duration, coupled with large amounts of rainfall.

8.9 SEISMIC AND GEOTHERMAL DISRUPTIVE POTENTIAL

The seismic risk for these mills is very low. In the event of an earthquake, effective peak ground acceleration for the region is estimated at 0.06 g. No known volcanic systems are located nearby (U.S. Geological Survey 1970).

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9.0 SOUTHERN ROCKY MOUNTAINS

The Southern Rocky Mountains region covers an area of approximately 124,000 km^2 (48,000 square miles) that includes most of central Colorado, as well as parts of southern Wyoming and northern New Mexico (see Figure 4.1). Three conventional uranium mills currently operate in the southern Rockies: the Cotter Mill at Canon City, Colorado, the Homestake, Pitch Mill in the Marshall Pass area, and the Hansen Mill in the Tallahassee Creek area (U.S. Department of Energy 1980).

Environmental parameters of the region include an arid climate with wide seasonal variations of temperature and wind speed. Storms are common and occasionally spawn tornados. The area has a moderately high seismic and geothermal potential. Natural factors most likely to disrupt uranium tailings are flash flooding, tornado-force winds, and seismic disturbances.

9.1 REGIONAL CLIMATOLOGY AND METEOROLOGY

The climate of the Southern Rocky Mountains ranges from semiarid to moderate subpolar. Daily and seasonal temperature variations are wide. Strong winds and storms are frequent. Winds in the region are usually from the south and have an annual average speed of about 4 m/sec (10 mph), whereas gusts can reach 24 m/sec (60 mph). The mean annual frequency of tornados in the region, documented between 1953 and 1962, ranges from 0 to 0.7 (Thom 1963).

Because of the high altitude of the region, seasonal temperatures tend to be extreme, ranging from highs of 32°C to lows near -50°C. Transitional periods in spring and fall have warm days and cool nights. Annual average precipitation ranges from 25 to 80 cm (10 to 32 in.) mostly from summer thunderstorms. Annual evaporation ranges from 100 to 150 cm/year (40 to 60 in.) and exceeds precipitation, giving the region a dry climate (Argonne National Laboratory 1979).

9.2 REGIONAL HYDROLOGY

Surface water in the Southern Rocky Mountains region generally drains east or west from the continental divide. The Rio Grande, Arkansas, and Upper Colorado Rivers comprise the major surface drainage. Ground water is typically restricted to unconfined aquifers in intermontane basins.

Surface water near the Cotter Mill at Canon City, Colorado, is drained by the Arkansas River Valley. A wide variation of flow rates exists in the Arkansas River because of rapid runoff from spring snowmelt and flash flooding during summer thunderstorms. Homestake's Mill, being developed at Marshall Pass, is located in the Marshall Creek drainage near its confluence with Indian Creek. Annual flow rates of Marshall Creek in this area average 0.4 m^3/sec (13 cfs) (U.S. Forest Service 1978). The Hansen Mill is located in the Tallahassee Creek and Salt Creek drainage areas (U.S. Nuclear Regulatory Commission 1981).

Ground water of southern Colorado is largely contained in unconsolidated material in mountain valleys and basins. Basement rocks yield some water within fracture zones.

9.3 REGIONAL SOILS

Dominant soils of the Southern Rocky Mountains region are Alfisols and Entisols. (The Alfisols are the most prevalent.) These soils are typical of temperate regions and form on slopes of mountains under coniferous forests. Alfisols in central Colorado tend to have a medium to high base content. An organic rich layer at the surface overlies an argillic horizon rich in layered lattice clay. Entisols are younger, with poor horizon development and nearly neutral pH (Buol, Hole and McCracken 1973).

Soils in the area of Canon City, near the region's only active uranium mill, are of shallow to medium depth, and are well drained on moderate to steep slopes (U.S. Department of Agriculture 1972). The soil near the Marshall Pass Mill is a deep loam formed from fine-grained igneous materials. Generally, this soil is slightly acidic, low in organic material, and has a color (U.S. Forest Service 1978).

9.4 REGIONAL GEOLOGY AND GEOMORPHOLOGY

Thick accumulations of Paleozoic and Mesozoic marine and nonmarine sedimentary sequences occur throughout much of the Southern Rockies region. Subsequent deformation during the Laramide Orogeny resulted in formation of the Front Range, Wasatch, and Sangre de Cristo mountain ranges. Typically these mountains are characterized by having cores of Precambrian crystalline rocks flanked by steeply dipping Paleozoic and Mesozoic sedimentary strata.

Igneous intrusives and extrusives of late Mesozoic and Tertiary are also present. Intermontane basins throughout the region contain Tertiary continental sediments and volcanics. Topography of the region is rugged, with over 800 peaks, ranging from 3300 to 4200 m (10,800 ft to 13,800 ft). Over 50 peaks exceed 4200 m (13,800 ft). Relatively flat intermontane basins separate the mountain ranges.

9.5 REGIONAL SEISMICITY AND GEOTHERMAL POTENTIAL

Occurrences of faults along the Southern Rocky Mountains have led to earthquakes greater than intensity VI (MM). In addition, much of central Colorado is classified as a region of high seismicity (Coffman 1973). Horizontal acceleration throughout the region has a 90% probability of not exceeding 10% of gravity in 50 years (U.S. Geological Survey 1970).

Although no large igneous bodies have been identified, numerous hot water systems and surface hot springs are scattered throughout central Colorado. Much of the southern part of the region is classified as having potential for development of low temperature geothermal water (U.S. Geological Survey 1978).

9.6 MILL SITE CHARACTERISTICS

Three mills are located in the Southern Rocky Mountains: Pitch Project (Homestake Mining Co.), Canon City Mill (Cotter Corp.), and Hansen Mill (Cyprus Mines Corp.). Together they process about 6350 MT/day (6980 tpd) of ore. Available information on the physical characteristics of the mills is summarized in Table 9.1.

9.6.1 Pitch Project (Homestake Mining Co.)

The Pitch Project is located in the Marshall Pass area and will process about 550 MT/day (600 tpd) of ore using an alkaline-leach process. Waste will be deposited in a 714 m (2340 ft) long clay-core dam enclosing 28 ha (69 acres). Sand, gravel, and mine overburden will line the downstream face of the dam (slope = 3H:1V). The upstream slope will be lined with coarse tailings, creating a slope of 2.5H:1V. The dam will be 43 m (142 ft) in height in the final stages of mill operation (Homestake Mining Company 1977).

9.6.2 Canon City Mill (Cotter Corp.)

The Canon City Mill, located about three miles south of Canon City, recovers both uranium and vanadium through a two-stage acid leach. The new mill, completed in 1979, replaced Cotters older alkaline leach mill and processes up to 1300 MT/day (1430 tpd) of ore. The new tailings dam is being constructed in stages by the downstream method. The dam will have a length of 1500 m (4900 ft), a crest width of 9 m (30 ft), and a depth of 33 m (108 ft). An upstream catchment pond will divert surface runoff from the impoundment. The pond occupies 81 ha (200 acres) (U.S. Nuclear Regulatory Commission 1980b).

9.6.3 Hansen Mill (Cyprus Mines Corp.)

The Hansen Mill, located about 32 km (20 miles) northwest of Canon City, Colorado, processes ore at a capacity of 4100 MT/day (4510 tpd). The mill uses a conventional acid-leach recovery process. The proposed tailings are slurried to the tailings cells at about 50% solids with excess liquid recycled. The tailings cells are head-of-valley impoundments consisting of three cells constructed, filled, and reclaimed in series. Excavation cut slopes will be 4H:1V with cell depths of 33 m (110 ft) and embankment heights of 24 m (80 ft) above the original valley floor. The ponds will be reclaimed to a slope of 6H:1V. Surfaces of the reclaimed impoundment will be revegetated. Open cut spillways will be designed to pass flood flows through the sides of cells and to prevent flood damage (U.S. Nuclear Regulatory Commission 1981).

9.7 PRECIPITATION AND POTENTIAL FLOOD STRESSES

The climate of this region is extremely variable, depending on the elevation. The high altitude areas have the greatest precipitation; the low altitude areas have the least precipitation. A common feature for all elevations is high-intensity precipitation with approximately 50% of the runoff caused

TABLE 9.1. Physical Characteristics of Mills in the Southern Rockies

Mill Characteristics	Cotter [a,b]	Homestake [c]	Cyprus [d]
Location	105°13'W 38°24'N	38°22'N 106°21'W	NA
Type of Pond	A	A	C
Tailings Area (ha)	81	28	90
Tailings Dimensions (m)	NA	670 x 520	915 x 1500
Embankment:			
Material	Borrow	Earth and rock fill with clay-core	Earthen
Slope	NA	3H:1V	4H:1V
Height (m)	33	43	24
Site Elevation (MSL--m)	1780	2800	2500
Leach Process	Acid	Akaline	Acid
Ore Process Rate (MT/day)	1300[e]	550	4100

(a) Minerals Resources Waste Management Team (1980)
(b) U.S. Nuclear Regulatory Commission (1979e)
(c) U.S. Forest Service (1978)
(d) U.S. Nuclear Regulatory Commission (1981)
(e) U.S. Nuclear Regulatory Commission (1980a)

KEY

Type of Pond: A--above ground, with dikes
B--natural or excavated pits
C--lined cells or trenches
ha--hectare
H:V--horizontal:vertical
m--meter
MSL--mean sea level
MT--metric tonne
NA--not available

by thunderstorms. In many areas, including the Pitch Project site, a high potential exists for flash flooding of small streams and normally dry washes as a result of snowmelt and rainstorms. However, the position of the Homestake Pitch Project at the head of most streams minimizes the flood risk. Flood parameters are shown in Table 9.2.

All of the mills use above-ground impoundments with tailings dams. At Pitch Project the dam is located in Hale Gulch, which is an old tributary of Marshall Creek. A diversion ditch was constructed to collect runoff. An upstream catchment pond controls runoff for the Canon City Mill. Diversion ditches direct runoff away from tailings at the Hansen Mill. Without these diversion structures, the mills would be susceptible to high rates of surface runoff. Over the long term, the effects of disruptive forces caused by flooding at these sites will depend largely on the integrity of the diversion ditches.

9.8 EOLIAN DISRUPTION POTENTIAL

The area is characterized by moderate winds with potential for high winds. Tornado probability is low. Because of the damp climate, the effects of wind erosion are reduced. Eolian disruption parameters are summarized on Table 9.3.

9.9 SEISMIC AND GEOTHERMAL DISRUPTION POTENTIAL

Seismic and geothermal disruption potentials are listed on Table 9.4. Although the sites are in an area of both geothermal and tectonic activity, no major disruptive events have occurred in the recent past. Maximum ground acceleration is estimated at 0.05 g for the region (Nelson and Shepherd 1978). An evaluation of the Hansen Mill reports a maximum-expected ground acceleration of 0.19 g. However, a 50,000-year probability is given for a potential earthquake with a maximum bedrock acceleration of 0.53 g along a nearby fault (U.S. Nuclear Regulatory Commission 1981).

TABLE 9.2. Flooding Parameters for Mills in the Southern Rockies

Parameters	Cotter[a,b]	Homestake[c]	Cyprus[d]
Nearest Stream	Sand Creek	Marshall Creek	Salt Creek
Drainage Area for Stream (km^2)	13	83	NA
Distance to Stream (m)	NA	750	0
Stream Elevation (MSL--m)	NA	2680	2500
Site Elevation (m)	NA	2800	2500
Elevation Difference (m)	NA	120	0
Stream flow:			
Mean Ephemeral (l/sec)	NA	225	Intermittent
Maximum (m^3/sec)	NA	1.6	NA
Slope of Surrounding Area (%)	5 to 40	10 to 30	3 to 25
Vegetation Density	Sparse	NA	Moderate
Vegetation Type	Grasses, juniper, and pine	Sagebrush and grasses	Grasses, brush, and pine
Precipitation:			
Mean Annual (cm)	30	40 to 50	53
Maximum Annual Recorded (cm)	60	NA	76
Snowfall (cm)	93	NA	300
Period of Record (yr)	30 to 60	16	4 to 5
Evaporation:			
Mean Annual (cm)	NA	71	86
Period of Record (yr)	NA	1	4
PMP	NA	NA	NA
PMT	NA	NA	33 in 1 h (site)
Tailings Pond			
Drainage Area (ha)	NA	NA	270
Underlying Geology	Alluvial materials to 5 m which overlie sandstone embedded with shales and conglomerates	Deep soils underlain by sedimentary rocks	Alluvial materials, underlain by siltstone, sandstone, and claystone
Runoff Potential	High	NA	NA

(a) Minerals Resources Management Team (1980)
(b) Nalco Environmental Sciences (1977)
(c) U.S. Forest Service (1978)
(d) U.S. Nuclear Regulatory Commission (1981)

KEY

NA--not available
m--meter
sec--second
l--liter
h--hour
PMP--Probable Maximum Precipitation
PMT--Probable Maximum Thunderstorm

TABLE 9.3. Eolian Disruption Parameters for Mills in the Southern Rockies

Parameters	Cotter[a]	Homestake[b]	Cyprus[c]
Historical Wind Data: (m/sec)			
Mean Velocity	3.6 to 5	4 W, WSW	2.6
Maximum Gust	NA	NA	31 SW, NW
Maximum 100-yr Gust	NA	36	40
Angle Between Mean Wind Direction and Long Axis of Tailings (degrees)	NA	0	20
Width of Tails Pile Along Wind Direction (m)	NA	520	915
Location of Dams in Relation to Pond	NA	Southwest	Northwest
Storm Potential			
Tornado Frequency	NA	Very low	NA
Tornado Velocity	NA	NA	NA
Soil Characteristics:[d]			
Slope Range (%)	15 to 60	5 to 50	NA
Surface Texture	Medium to Coarse	Medium	NA
Depth to Bedrock	23 to >152	>152	NA
Depth to Water Table (in.)	>152	NA	NA
Permeability	Slow to Moderate	NA	NA
Soil Erodibility	Low	NA	NA
Wind Erosion Potential	Medium	Medium	NA

(a) Nalco Environmental Sciences (1977)
(b) U.S. Forest Service (1978)
(c) U.S. Nuclear Regulatory Commission (1981)
(d) Soil data not available in U.S. NRC environmental statements were obtained from:
- County general soil maps, Colorado Soil Conservation Service

TABLE 9.4. Seismic and Geothermal Disruption Potential for Mills in the Southern Rockies

Parameters	Cotter	Homestake	Cyprus
Distance to (km):			
Nearest Earthquake(a)	40	45	50
Nearest Active Fault(a)	30	35	45
Hydrothermal System ($1-10 \times 10^{18}$ J)(b)	112	40	50
Hydrothermal System ($>10 \times 10^{18}$ J)(b)	256	290	315
Igneous System ($100-10,000 \times 10^{18}$ J)(b)	256	290	315
Fault Length (km)(a)	130	130	130
Tailings Dam:			
Seismic Stability(c)	NA	NA	0.2 g

(a) U.S. Forest Service (1978)
(b) U.S. Geological Survey (1979)
(c) U.S. Nuclear Regulatory Commission (1981)

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APPENDIX

TOPOGRAPHIC FEATURES OF INDIVIDUAL MILLS

BEST DOCUMENT AVAILABLE

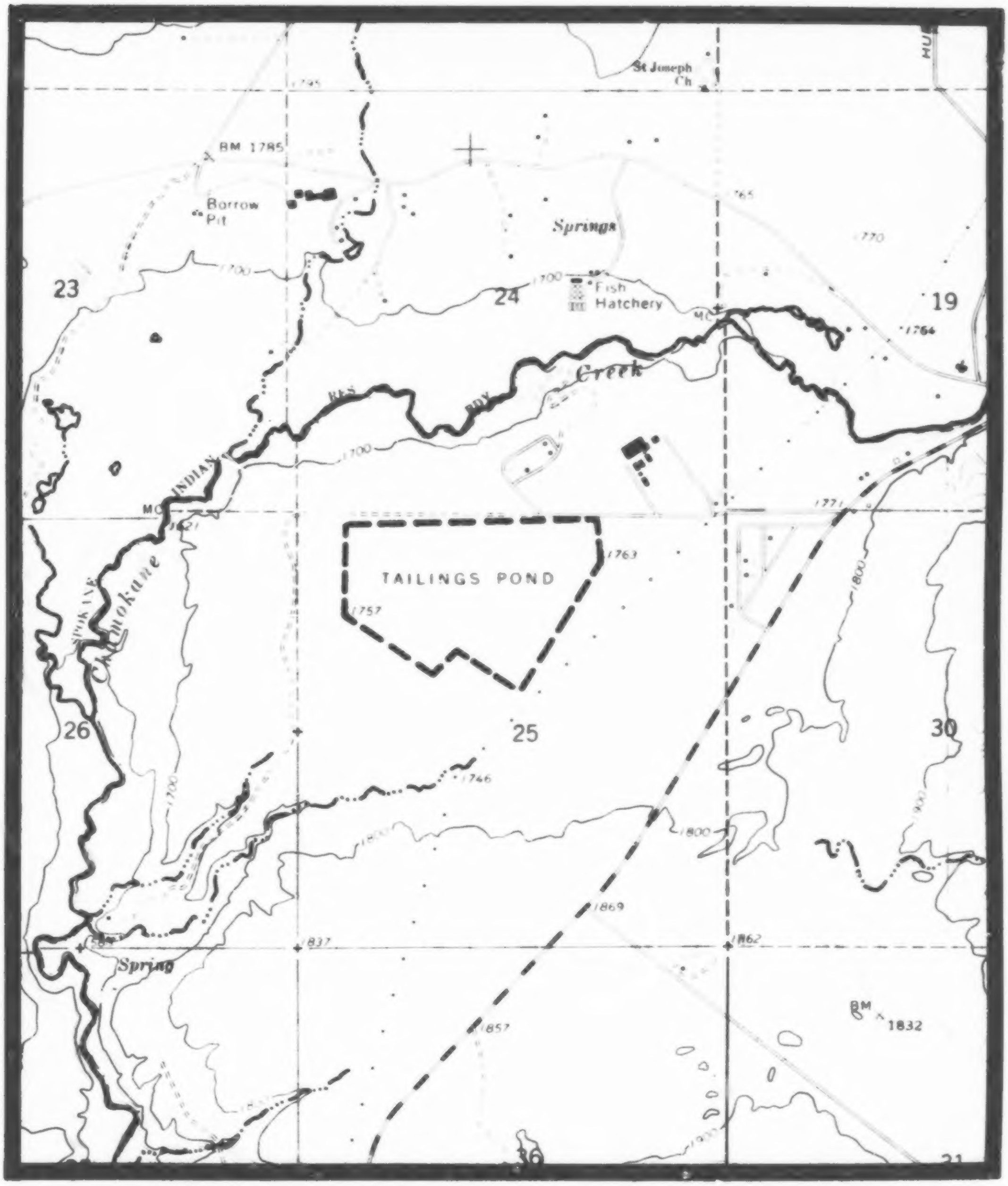
St Joseph Ch
BM 1785
Borrow Pit
Springs
Fish Hatchery
23
24
19
Creek
Chamokane
TAILINGS POND
1763
1757
26
25
30
1746
1800
1869
1862
1837
Spring
1857
BM 1832
36

FIGURE A.1. Location of Ford (Dawn Mining Co.) Mill Tailings (1:24,000) -- Ford Quadrangle, Washington

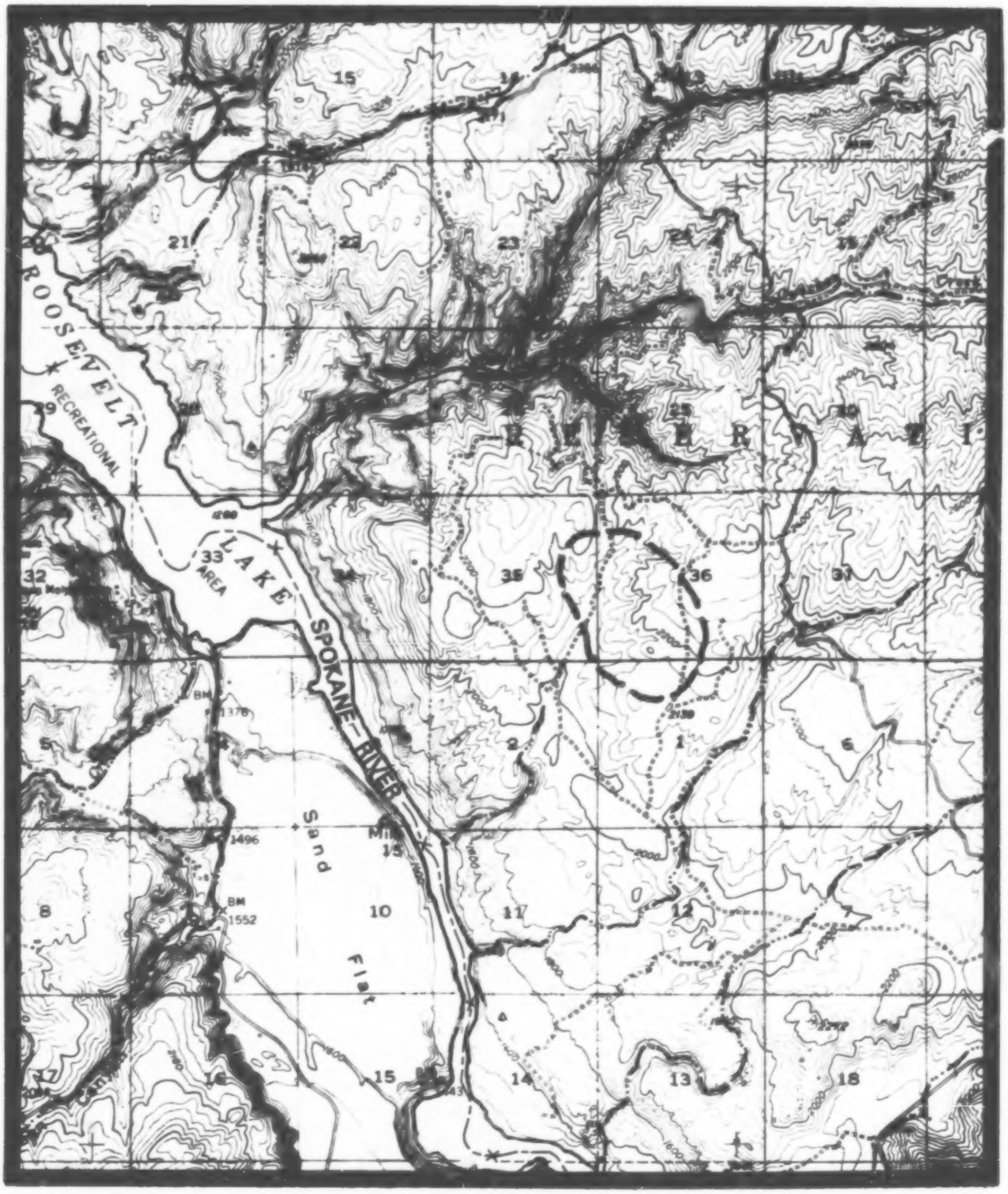
15
21
22
23
24
25
26
29
ROOSEVELT
RECREATIONAL
AREA
LAKE
33
32
34
35
36
SPOKANE RIVER
BM 1378
1496
BM 1552
Sand
Flat
Mill
2
1
6
5
8
10
11
12
15
14
13
16
17
18
Creek

FIGURE A.2. Location of Sherwood (Western Nuclear) Mill Tailings (1:62,500) -- Turtle Lake Quadrangle, Washington

[redacted]

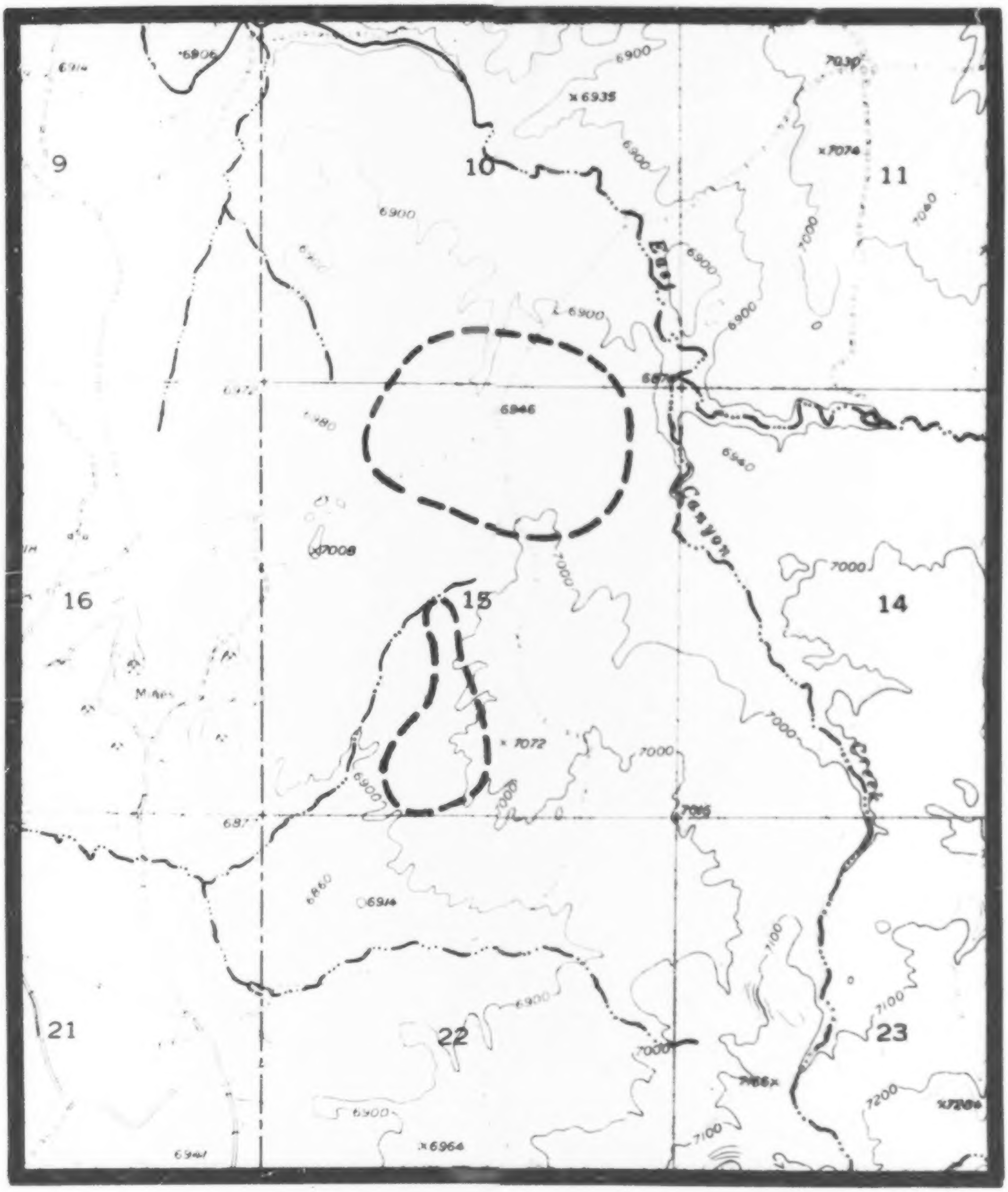
9
10
11
14
15
16
21
22
23
6906
6914
6900
x 6935
7030
x 7074
7000
6846
x7008
Canyon
Creek
7000
x 7072
6900
6914
6860
7100
7200
6964
6941

FIGURE A.3. Location of East Gas Hills (Union Carbide Corp.) Mill Tailings (1:24,000) -- Ervay Basin, SW, and Gas Hills Quadrangles, Wyoming

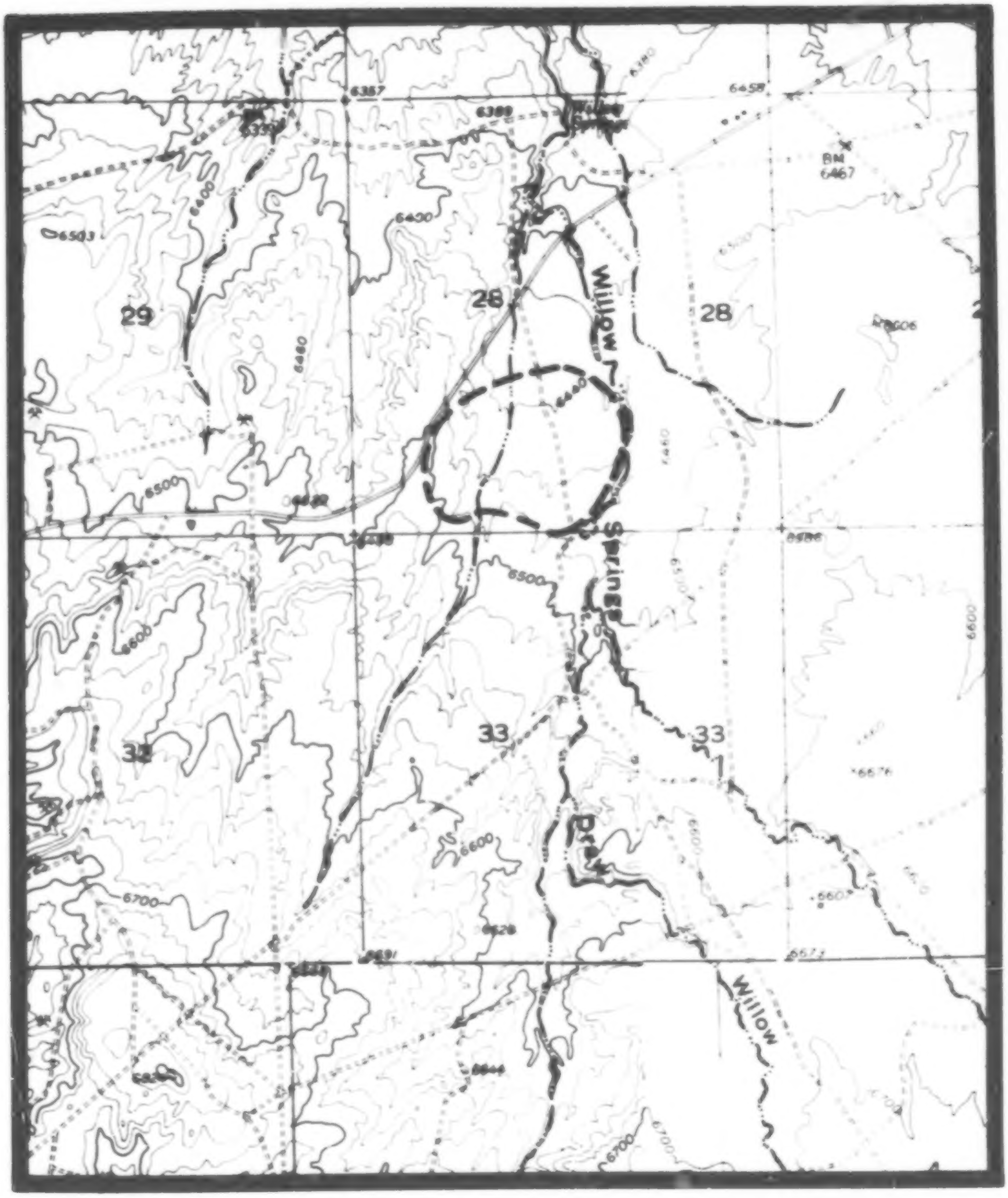
6387
6389
6458
BM
6467
6503
6400
6430
29
28
28
Willow
6480
6500
33
33
Springs
6600
32
Draw
6700
6628
6644
6691
Willow
6700

FIGURE A.4. Location of Gas Hills (Federal American Partners) Mill Tailings (1:24,000) -- Gas Hills and Puddle Springs Quadrangles, Wyoming

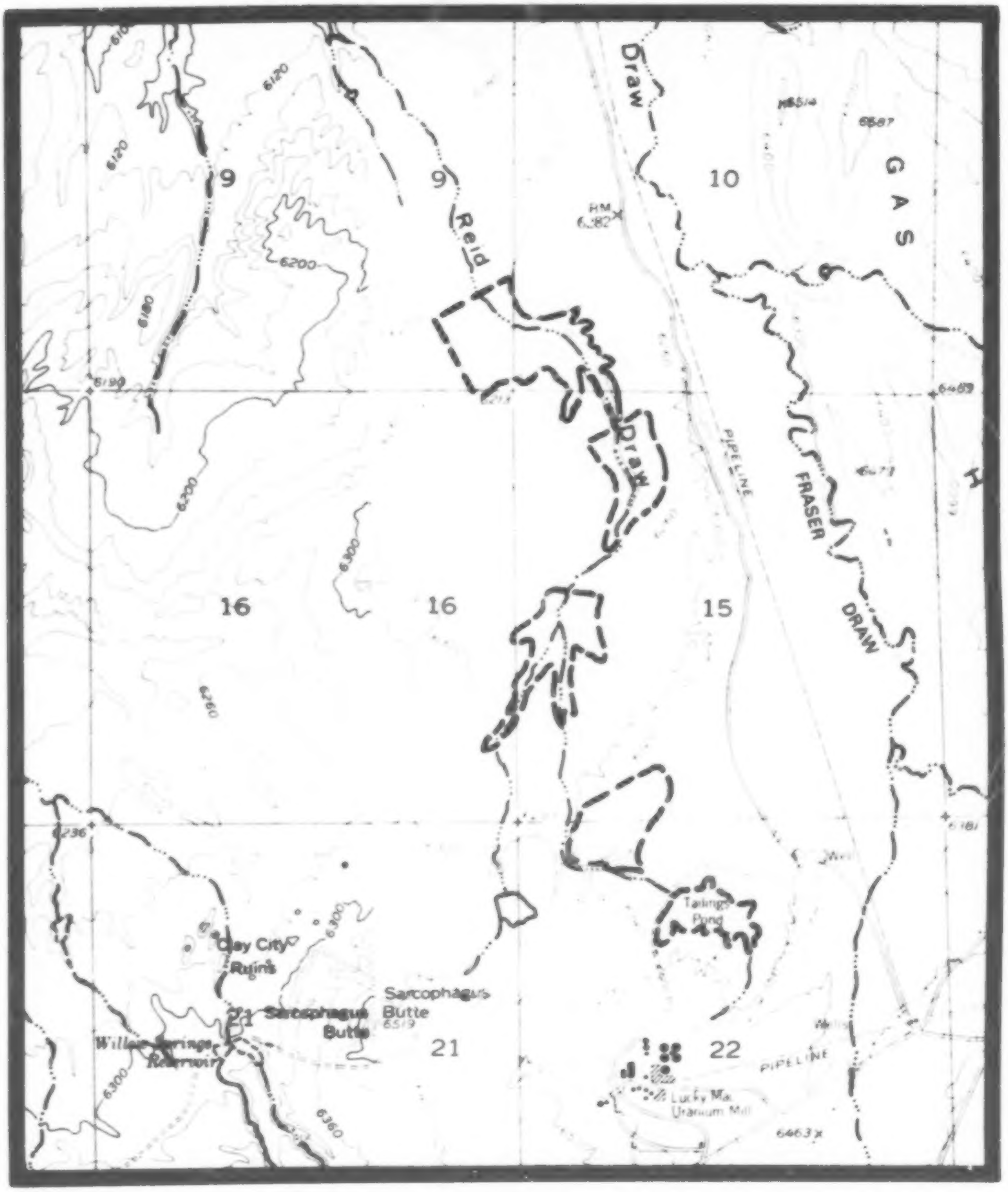
Draw
Reid
Draw
9
9
10
G A S
BM 6282
BM 6514
6587
6120
6120
6200
6180
6190
6469
PIPELINE
FRASER DRAW
6473
6300
6300
16
16
15
6260
6236
6181
Tailings Pond
Clay City Ruins
6300
Sarcophagus Butte
Sarcophagus Butte
6519
Willow Springs Reservoir
21
22
PIPELINE
Lucky Mc Uranium Mill
6463
6300
6360

FIGURE A.5. Location of Gas Hills (Pathfinder Mines Corp.) Mill Tailings (1:24,000) -- Puddle Springs and Moss Agate Quadrangles, Wyoming

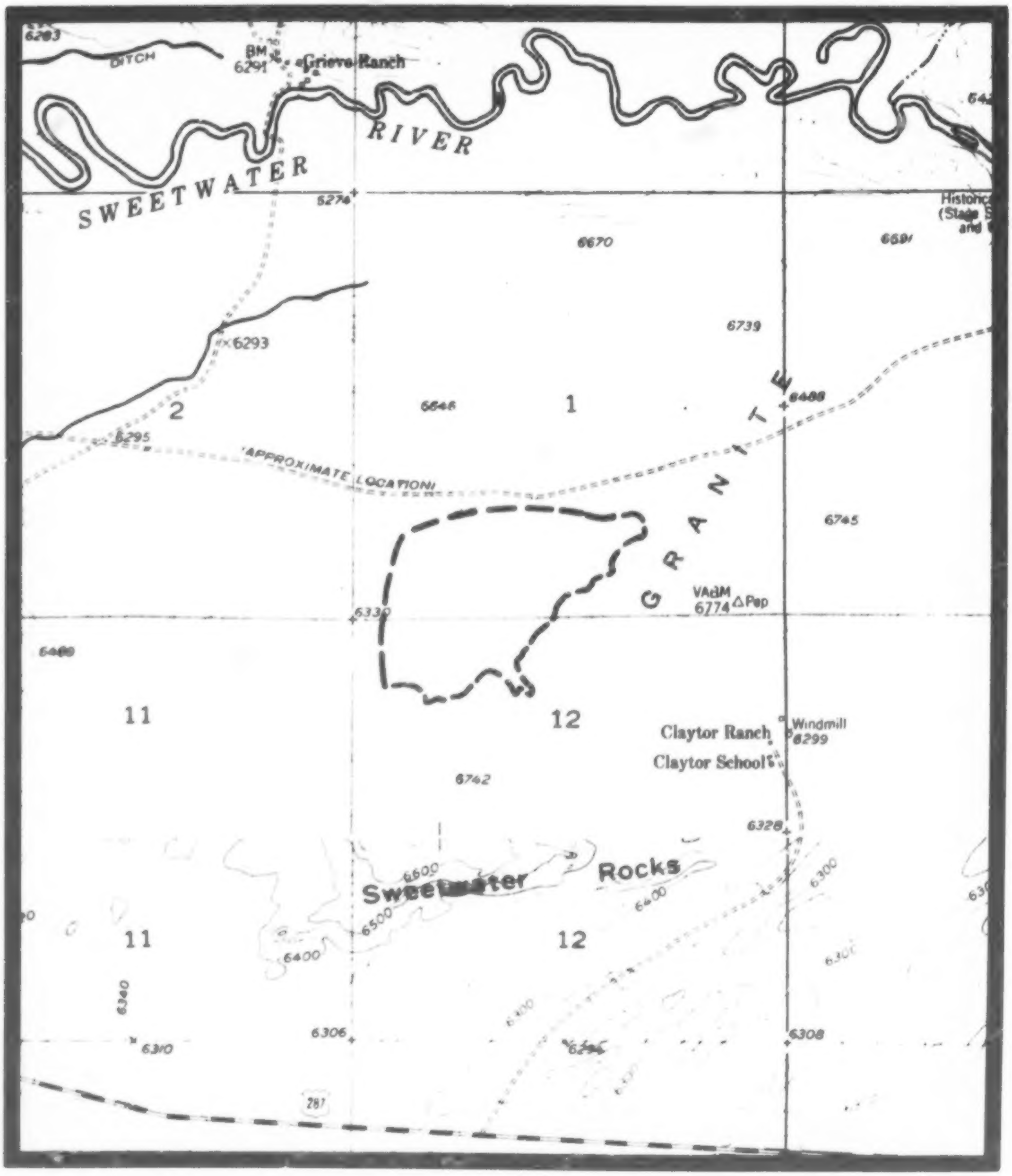
SWEETWATER RIVER
DITCH
BM 6291
Grieve Ranch
6283
5274
6670
6691
6739
6293
6488
2
1
6646
6295
APPROXIMATE LOCATION
GRANITE
6745
VABM 6774 Pep
6330
6480
11
12
Claytor Ranch
Claytor School
Windmill 6299
6742
6328
Sweetwater Rocks
6600
6500
6400
6300
11
12
6340
6310
6306
6308
287

FIGURE A.6. Location of Split Rock (Western Nuclear Corp.) Mill Tailings (1:24,000) -- Stampede Meadow and Jeffrey City Quadrangles, Wyoming

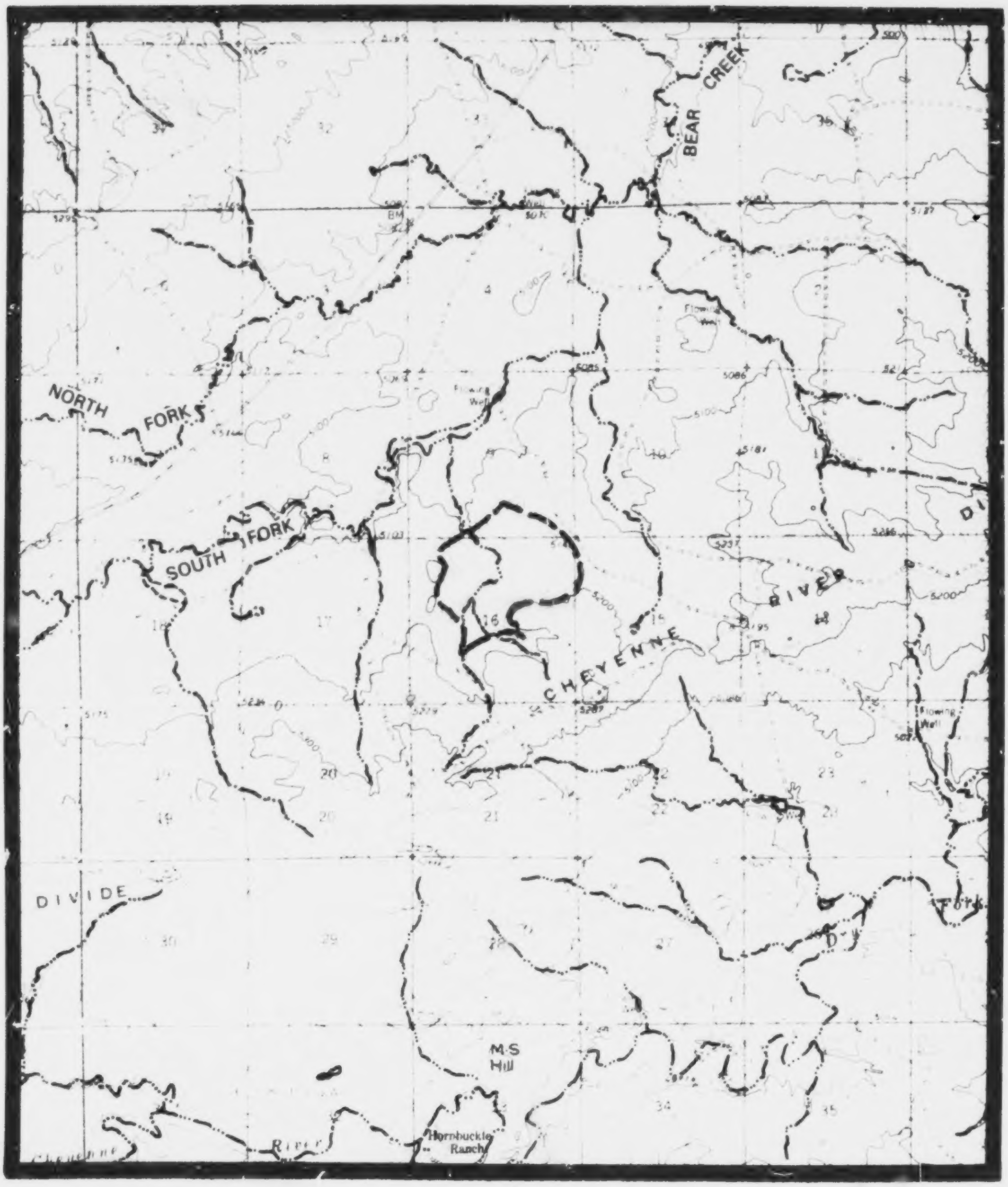
BEAR CREEK
NORTH FORK
SOUTH FORK
CHEYENNE RIVER
DIVIDE
Flowing Well
M-S Hill
Hornbuckle Ranch
River
Fork
16
17
20
21
22
23
27
28
29
30
34
35

FIGURE A.7. Location of Bear Creek (Rocky Mountain Energy Co.) Mill Tailings (1:62,500) -- Coal Draw Quadrangle, Wyoming

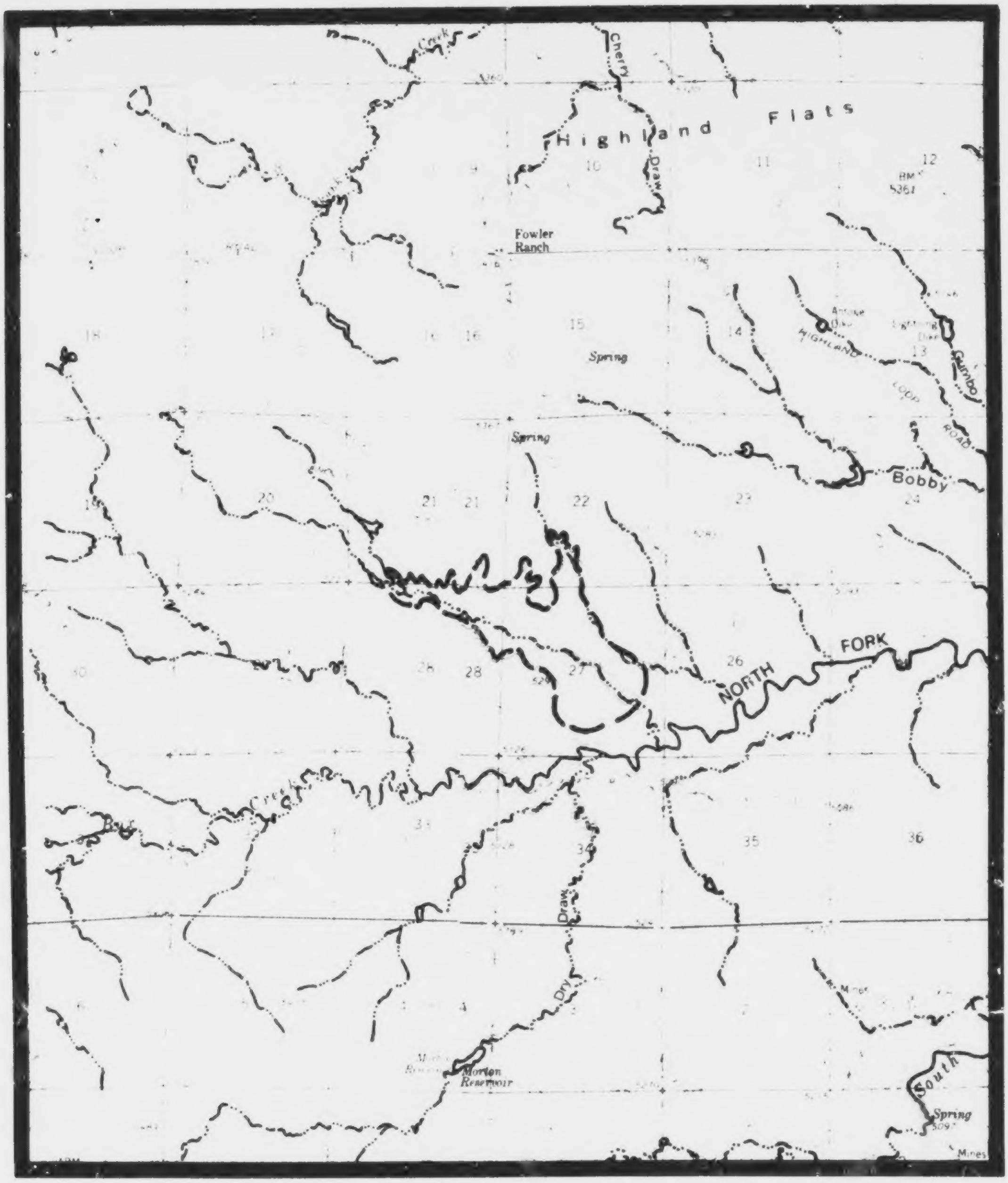
Cherry
Highland Flats
Draw
Fowler Ranch
Spring
Spring
HIGHLAND LOOP ROAD
Gumbo
Bobby
NORTH FORK
Creek
Dry Draw
Morton Reservoir
South
Spring
Mines

FIGURE A.8. Location of Highland (Exxon Corp.) Mill Tailings (1:62,500) -- Highland Flats and Bill Quadrangles, Wyoming

[redacted]

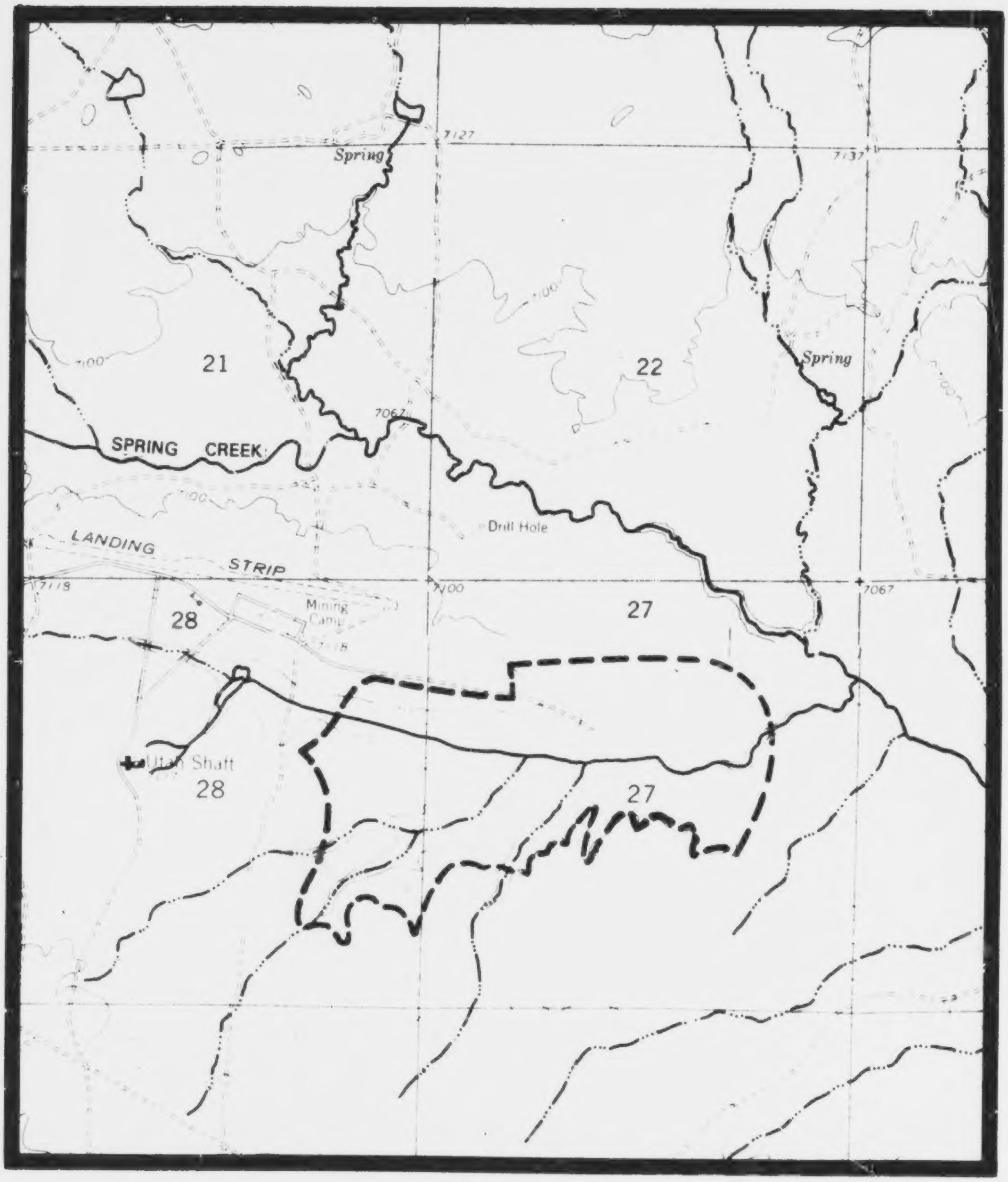
7127
Spring
7137
21
22
Spring
7100
7100
7067
SPRING CREEK
Drill Hole
LANDING STRIP
7118
28
Mining Camp
7118
7100
27
7067
Utah Shaft
28
27

FIGURE A.9. Location of Shirley Basin (Pathfinder Mines Corp.) Mill Tailings (1:24,000) -- Bates Creek Quadrangle, Wyoming

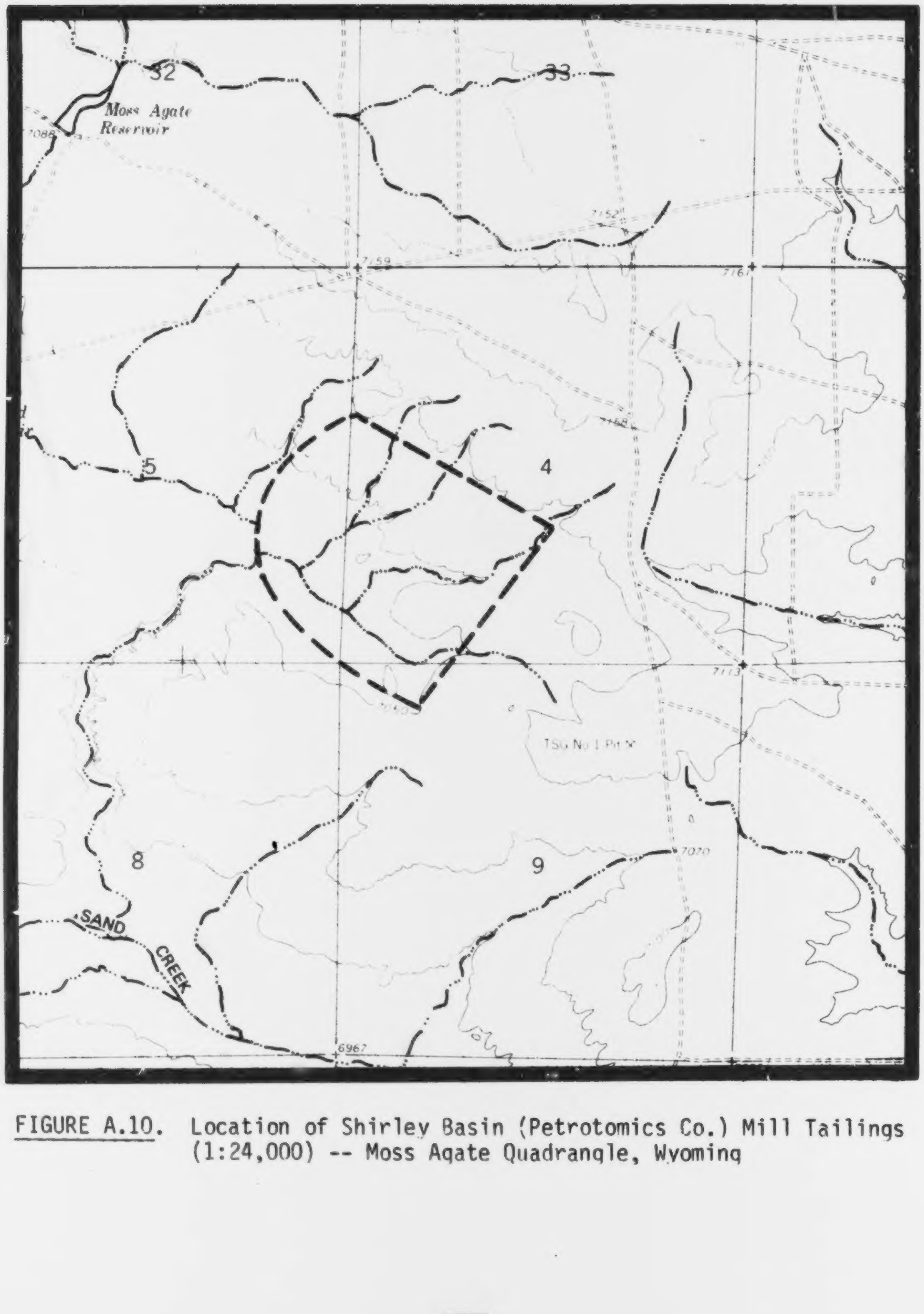
32
33
Moss Agate Reservoir
7088
7152
7159
7161
7158
5
4
7150
TSG No 1 Pit X
7113
8
9
7020
SAND CREEK
6967

FIGURE A.10. Location of Shirley Basin (Petrotomics Co.) Mill Tailings (1:24,000) -- Moss Agate Quadrangle, Wyoming

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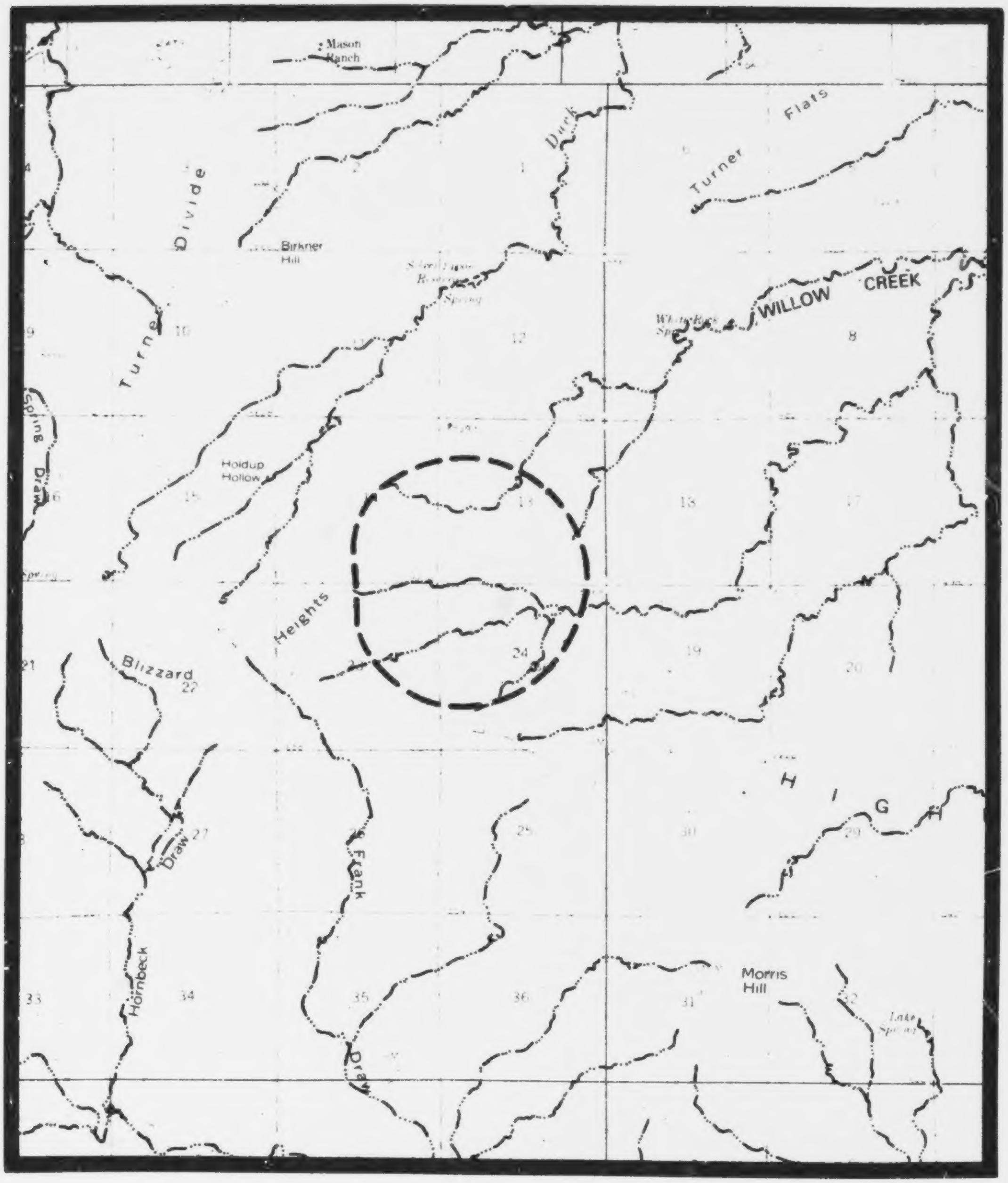
Mason Ranch
Duck
Turner Flats
Divide
Birkner Hill
Spring
WILLOW CREEK
Turner
Spring Draw
Holdup Hollow
Heights
Blizzard
Draw
Frank
Hornbeck
Draw
Morris Hill
Lake Spring
H I G H
2
1
6
10
12
8
16
15
14
13
18
17
21
22
24
19
20
27
25
30
29
33
34
35
36
31
32

FIGURE A.11. Approximate Location of South Powder River Basin (Kerr-McGee Nuclear Corp.) Mill Tailings (1:62,500) -- Highland Flats Quadrangle, Wyoming

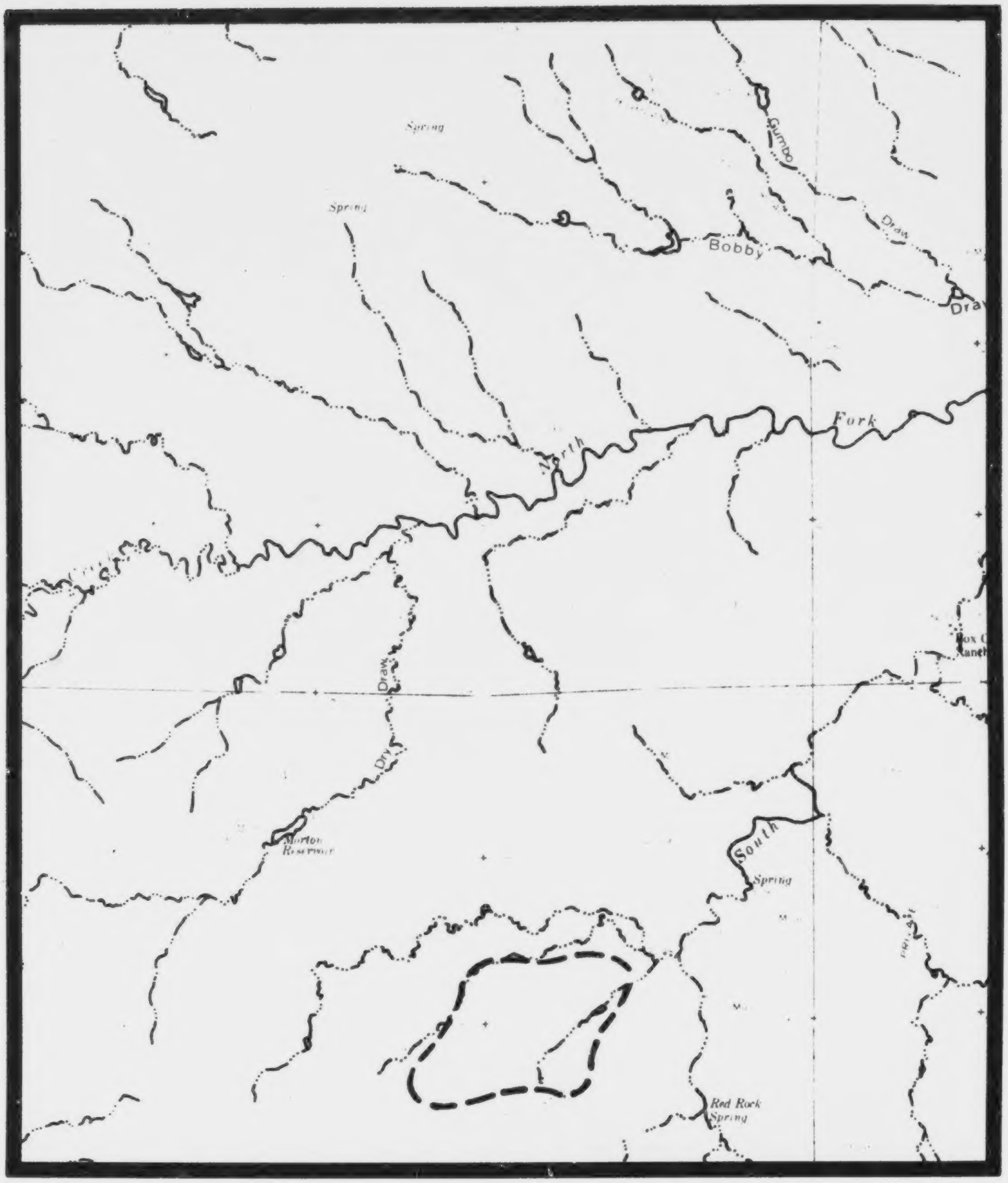
Spring
Spring
Gumbo
Draw
Bobby
Draw
North
Fork
Draw
Dry
Morton Reservoir
South
Spring
Red Rock Spring

FIGURE A.12. Location of Morton Ranch (Tennessee Valley Authority) Mill Tailings (1:62,500) -- Bill Quadrangle, Wyoming

[redacted]

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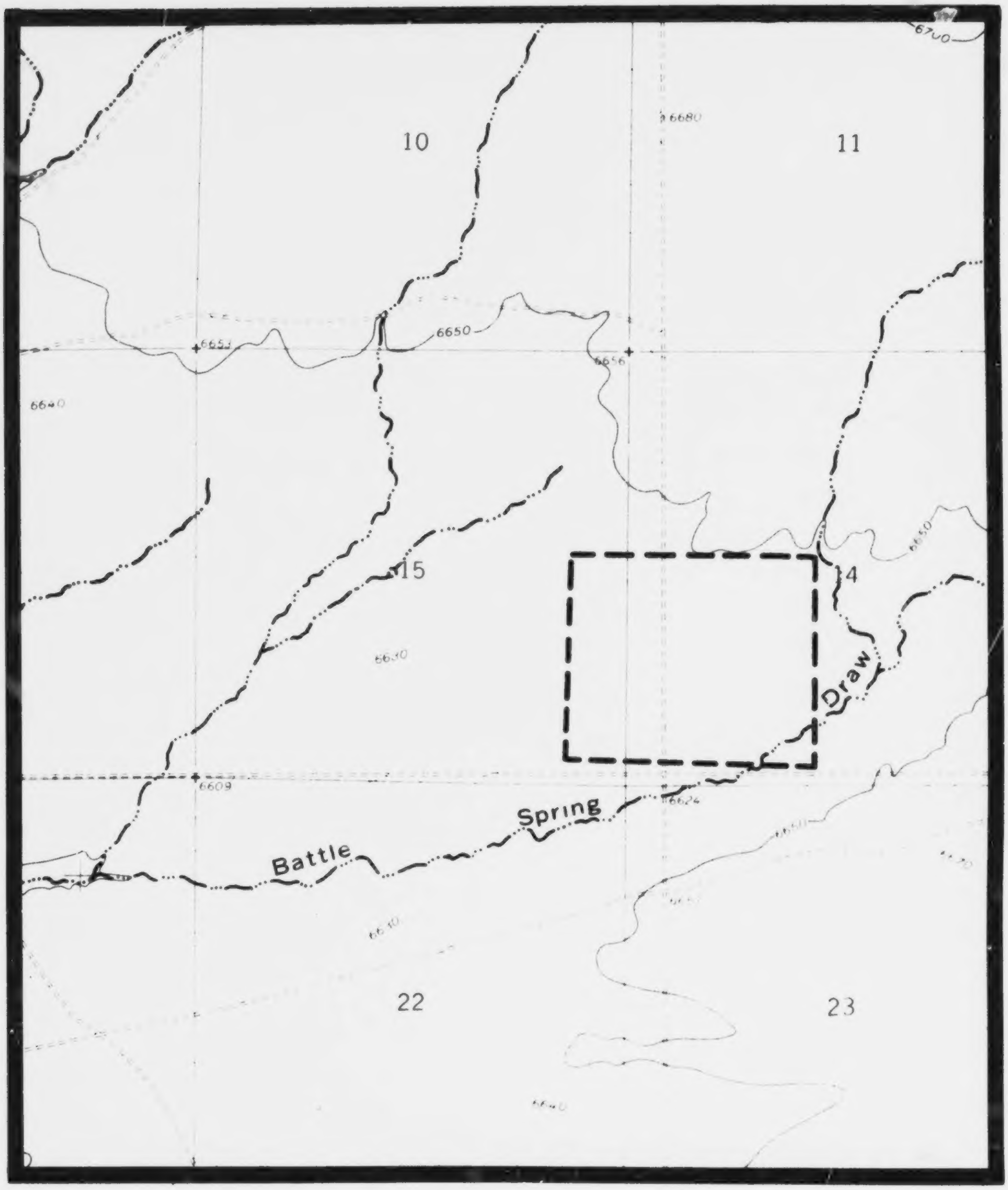
6700
6680
10
11
6653
6650
6656
6640
15
14
6630
Draw
6609
6624
Spring
Battle
6650
6640
22
23
6640

FIGURE A.13. Location of Sweetwater Uranium Project (Minerals Exploration Co.) Mill Tailings (1:24,000) -- Battle Springs Quadrangle, Wyoming

BEST DOCUMENT AVAILABLE

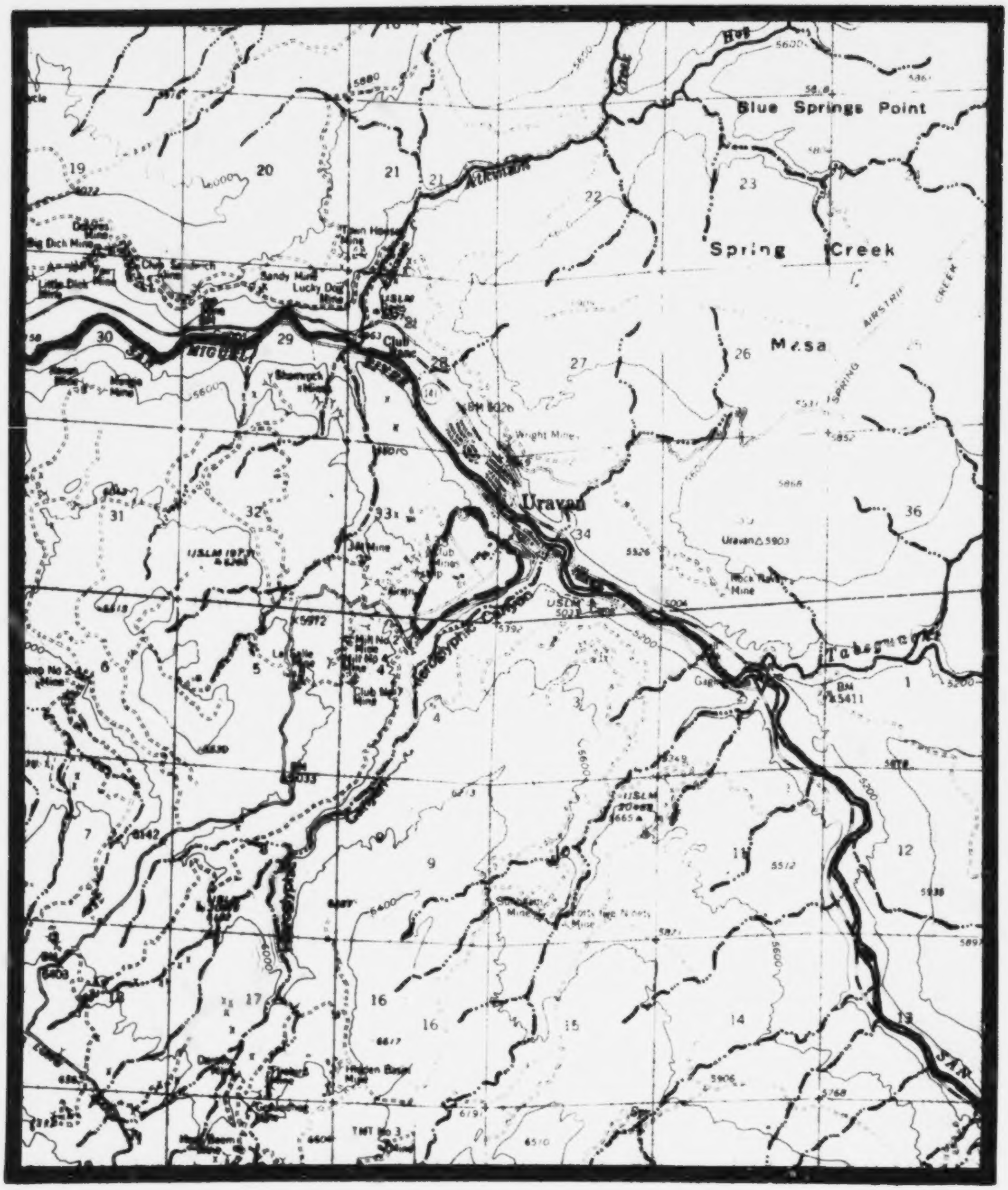
Blue Springs Point
Spring Creek
Mesa
Uravan
Atkinson
Big Dick Mine
Little Dick Mine
Sandy Mine
Lucky Day Mine
Wright Mine
San Miguel River
Tabeguache
Airstrip
Spring Creek
Uravan △ 5903
5600
SAN
19
20
21
22
23
26
27
28
29
30
31
32
33
34
36
1
2
3
4
5
6
7
9
10
11
12
13
14
15
16
17

FIGURE A.14. Location of Uravan (Union Carbide Corp.) Mill Tailings (1:62,500) -- Slick Rock Quadrangle, Colorado

[redacted]

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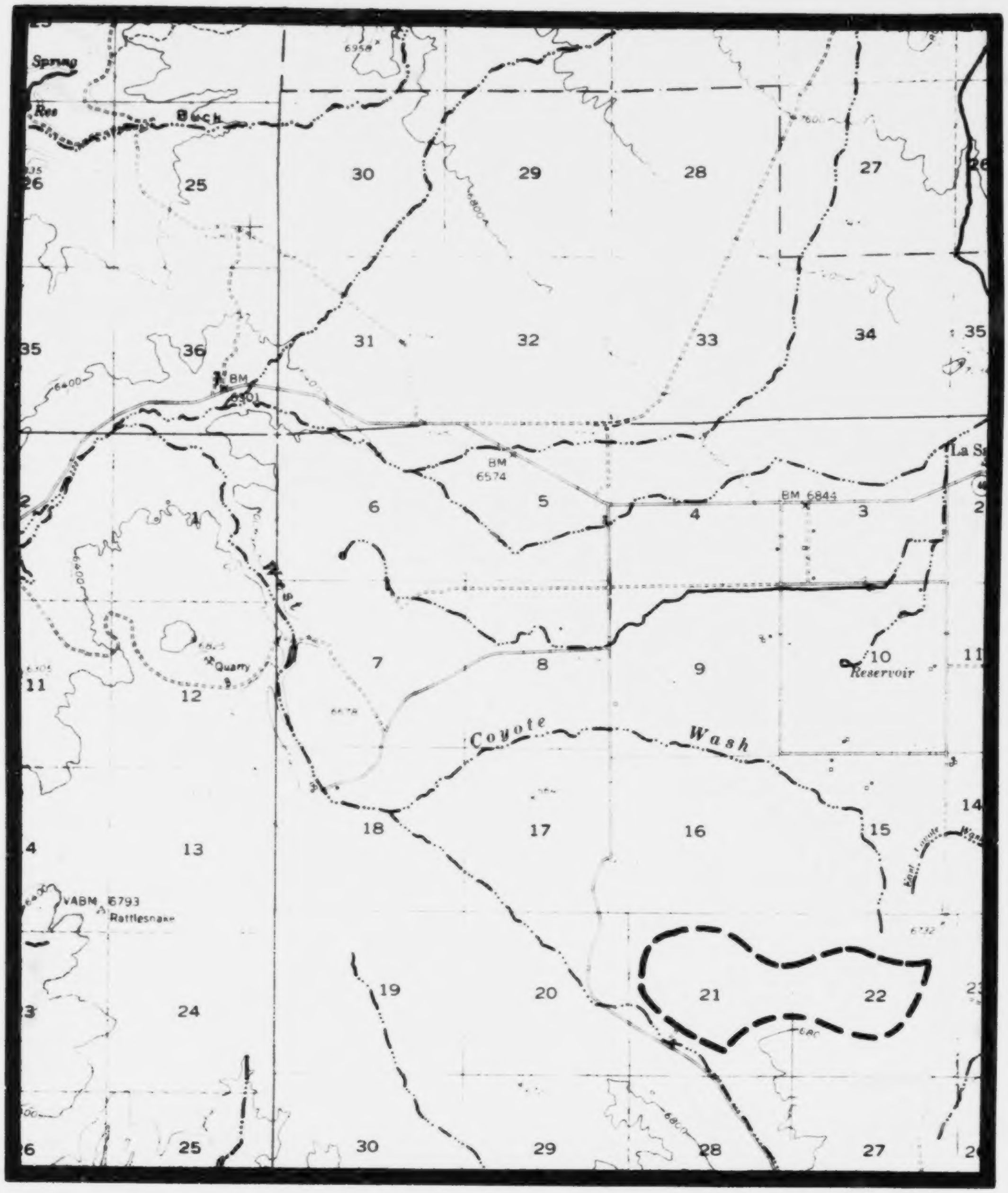
Spring
Res
Buck
30
29
28
27
26
25
31
32
33
34
35
36
BM
6400
BM 6574
6
5
4
3
2
BM 6844
La Sal
West
7
8
9
10
Reservoir
11
12
Quarry
Coyote Wash
14
15
16
17
18
13
VABM 6793
Rattlesnake
19
20
21
22
23
24
25
29
28
27

FIGURE A.15. Location of Lisbon Mine (Rio Algom Co.) Mill Tailings (1:62,500) -- La Sal Junction Quadrangle, Utah

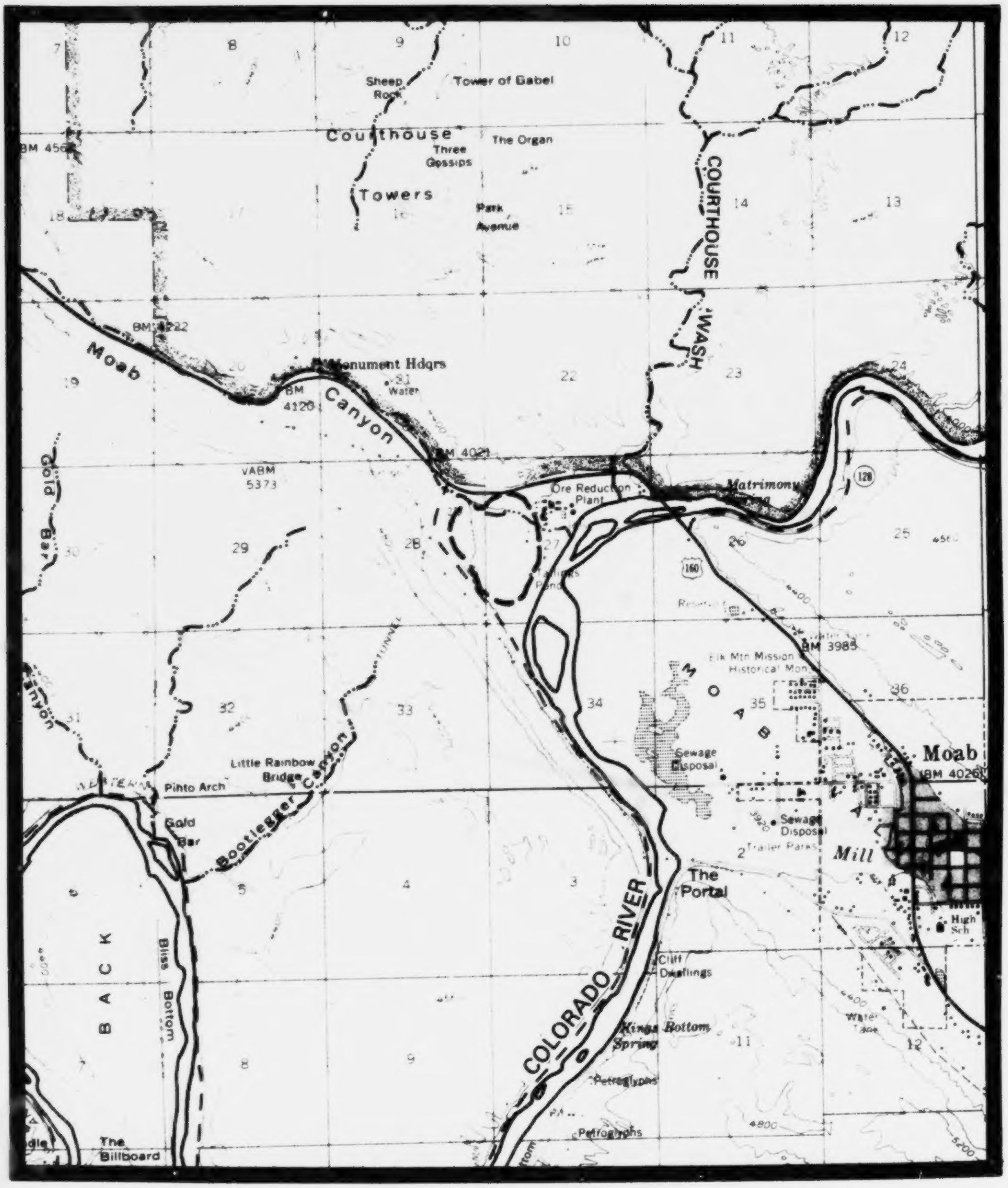
Sheep Rock
Tower of Gabel
Courthouse
Three Gossips
The Organ
Towers
Park Avenue
COURTHOUSE WASH
BM 4222
Moab
Monument Hdqrs
Water
BM 4120
Canyon
BM 4021
VABM 5373
Ore Reduction Plant
Matrimony Spring
Tailings Pond
128
160
BM 3985
Elk Mtn Mission Historical Mon
MOAB
Sewage Disposal
Moab
BM 4026
Mill
Trailer Parks
The Portal
High Sch
Little Rainbow Bridge
Pinto Arch
Bootlegger Canyon
Gold Bar
Gold Bar Canyon
BACK
Bliss Bottom
COLORADO RIVER
Cliff Dwellings
Kings Bottom Spring
Petroglyphs
The Billboard

FIGURE A.16. Location of Moab (Atlas Minerals Corp.) Mill Tailings (1:62,500) -- Moab Quadrangle, Utah

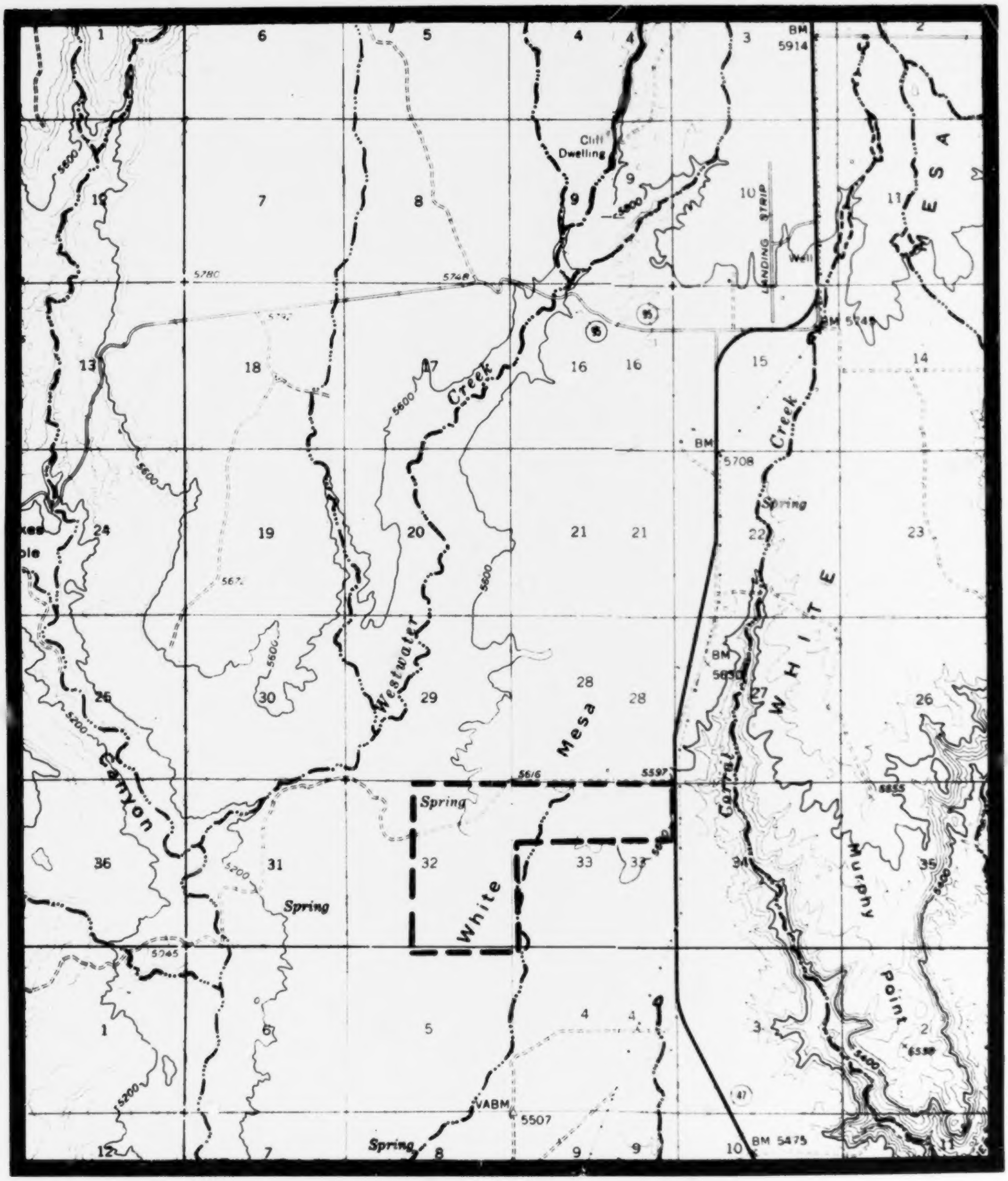
1
6
5
4
4
3
BM 5914
2
Cliff Dwelling
9
9
10
LANDING STRIP
Well
11
MESA
7
8
12
5780
5748
13
18
17
Creek
16
16
15
BM 5748
14
BM 5708
Creek
Spring
24
19
20
21
21
22
23
WHITE
Westwater
BM 5650
25
30
29
28
28
27
26
Mesa
Canyon
5616
5597
Spring
5855
Corral
36
31
32
33
33
34
35
Murphy
Spring
White
5245
Point
1
6
5
4
4
3
2
5538
VABM 5507
47
Spring
12
7
8
9
9
10
BM 5475
11
5600
5200
5400

FIGURE A.17. Location of White Mesa (Energy Fuels Nuclear, Inc.) Mill Tailings (1:62,500) -- Blanding and Brushy Basin Quadrangles, Utah

[redacted]

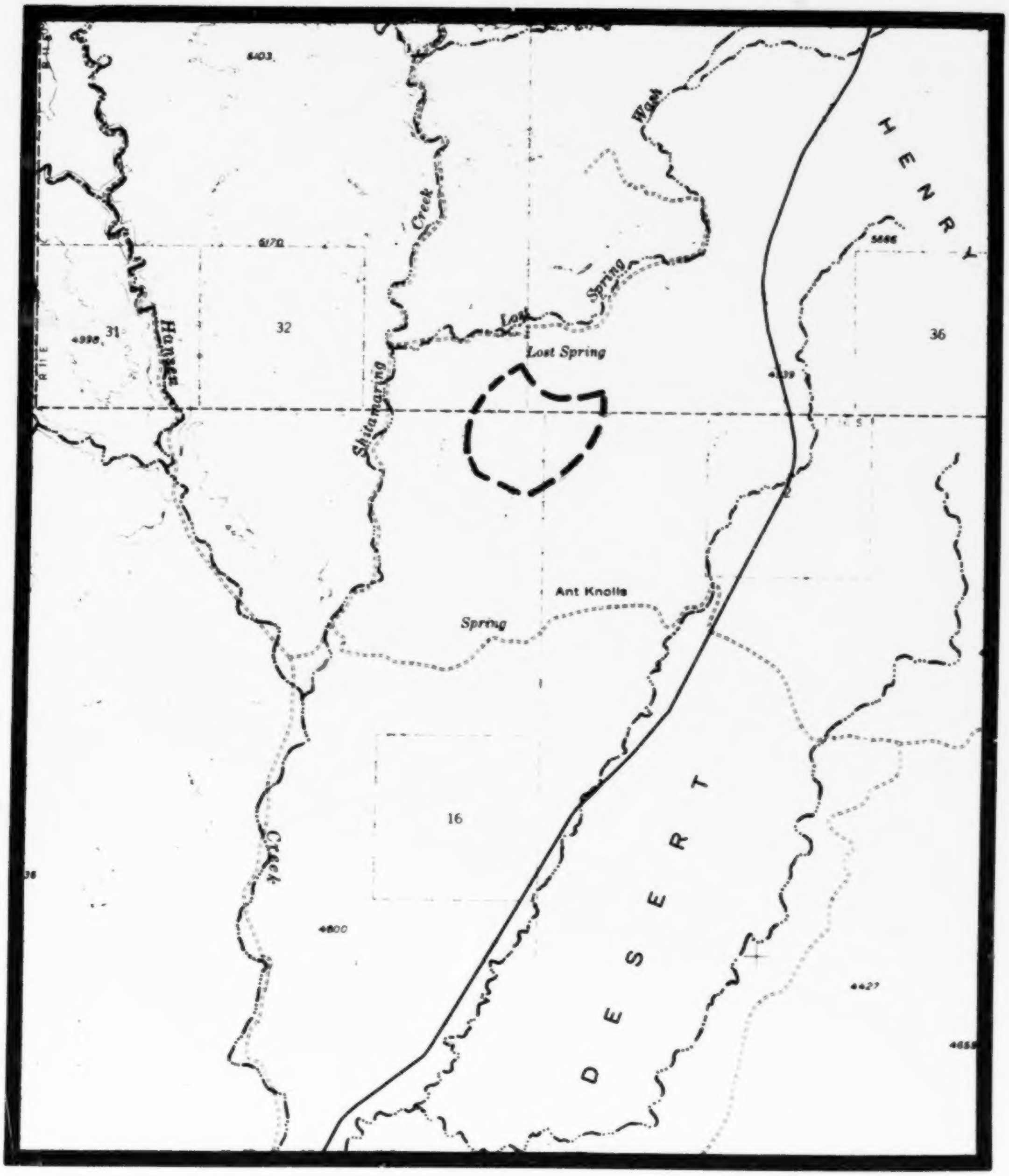
6103
6170
Creek
Wash
HENRY
Spring
Lost
Lost Spring
Hansen
Shitamaring
31
32
36
4998
5686
4439
Ant Knolls
Spring
16
Creek
4800
DESERT
4427
4658

FIGURE A.18. Location of Shootering Canyon (Plateau Resources Limited) Mill Tailings (1:62,500) -- Mt. Ellsworth Quadrangle, Utah

[redacted]

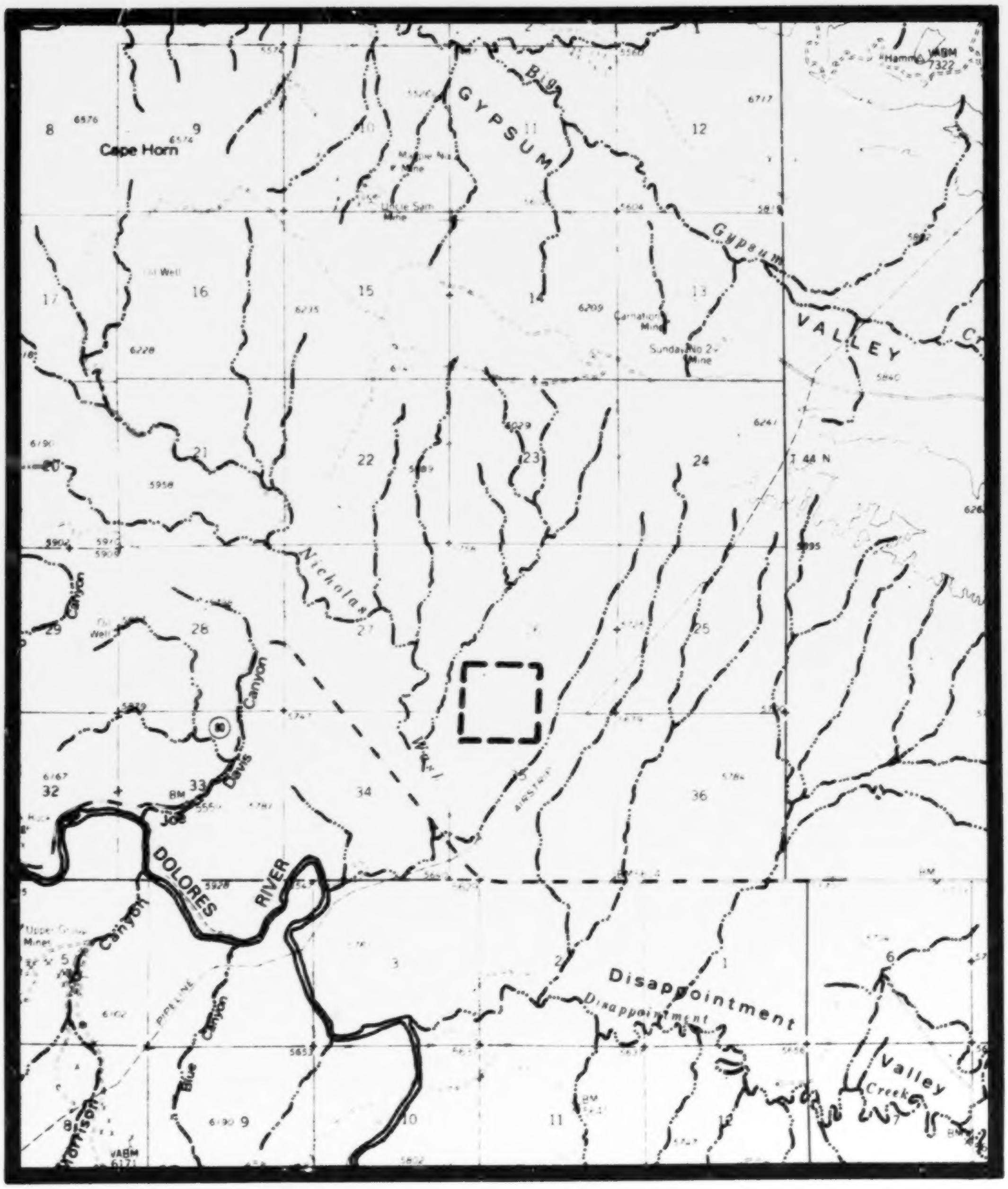
Cape Horn
Big
GYPSUM
Gypsum
VALLEY
Carnation Mine
Sunday No 2 Mine
Uncle Sam Mine
Nicholas
Canyon
Davis
Canyon
Joe
DOLORES
RIVER
Canyon
Blue
Canyon
PIPELINE
AIRSTRIP
Disappointment
Disappointment
Valley
Creek
T 44 N
VABM 7322
VABM 6171
8
9
10
11
12
15
16
17
14
13
21
22
23
24
20
28
29
27
25
32
33
34
35
36
1
2
3
5
6
7
8
9
10
11
12

FIGURE A.19. Location of San Miguel Project (Pioneer Uravan, Inc.) Mill Tailings (1:62,500) -- Slick Rock and Paradox Quadrangles, Colorado

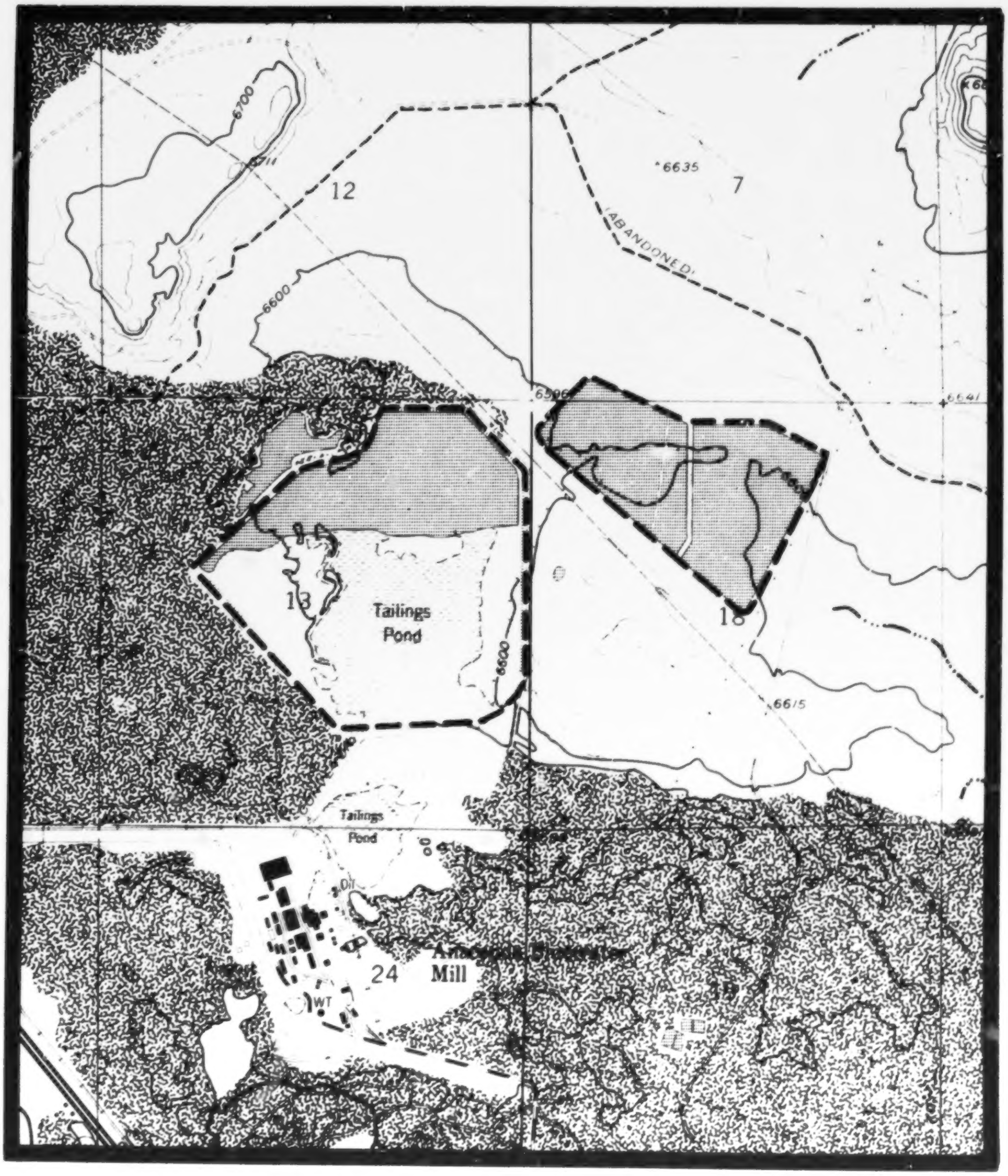
6700
12
6635
7
ABANDONED
6600
6596
6641
13
Tailings Pond
6600
18
6615
Tailings Pond
Oil
24
Mill
WT

FIGURE A.20. Location of Bluewater (Anaconda Co.) Mill Tailings (1:24,000) -- Bluewater Quadrangle, New Mexico

BEST DOCUMENT AVAILABLE

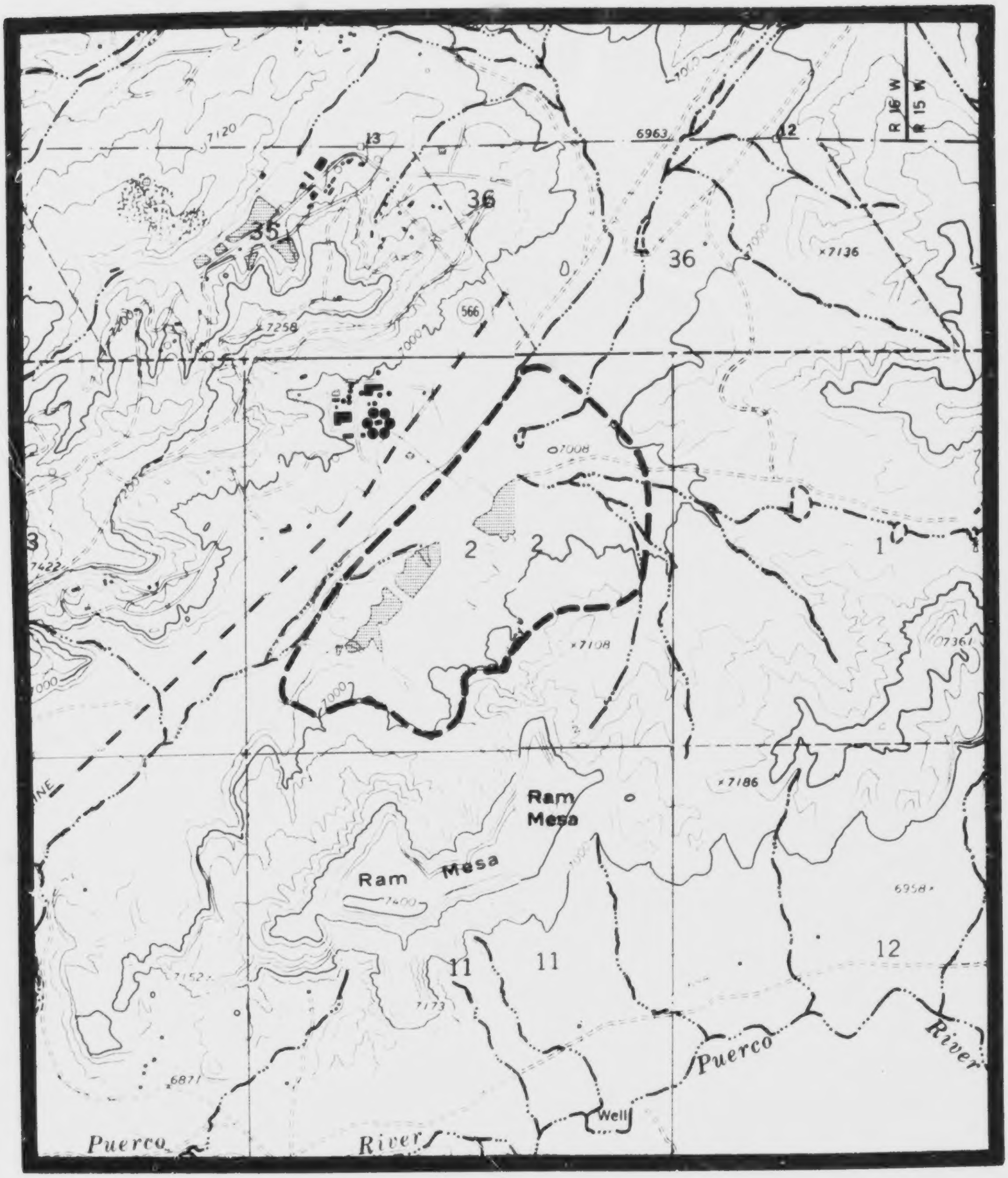
R 16 W
R 15 W
7120
13
6963
12
36
35
36
×7136
566
×7258
7000
7422
○7008
2
2
1
×7108
7361
7000
×7186
Ram Mesa
Ram Mesa
7400
6958×
12
11
11
7152
7173
6871
Puerco River
Puerco River
Well

FIGURE A.21. Location of Church Rock (United Nuclear Corp.) Mill Tailings (1:24,000) -- Hard Ground Flats and Pinedale Quadrangles, New Mexico

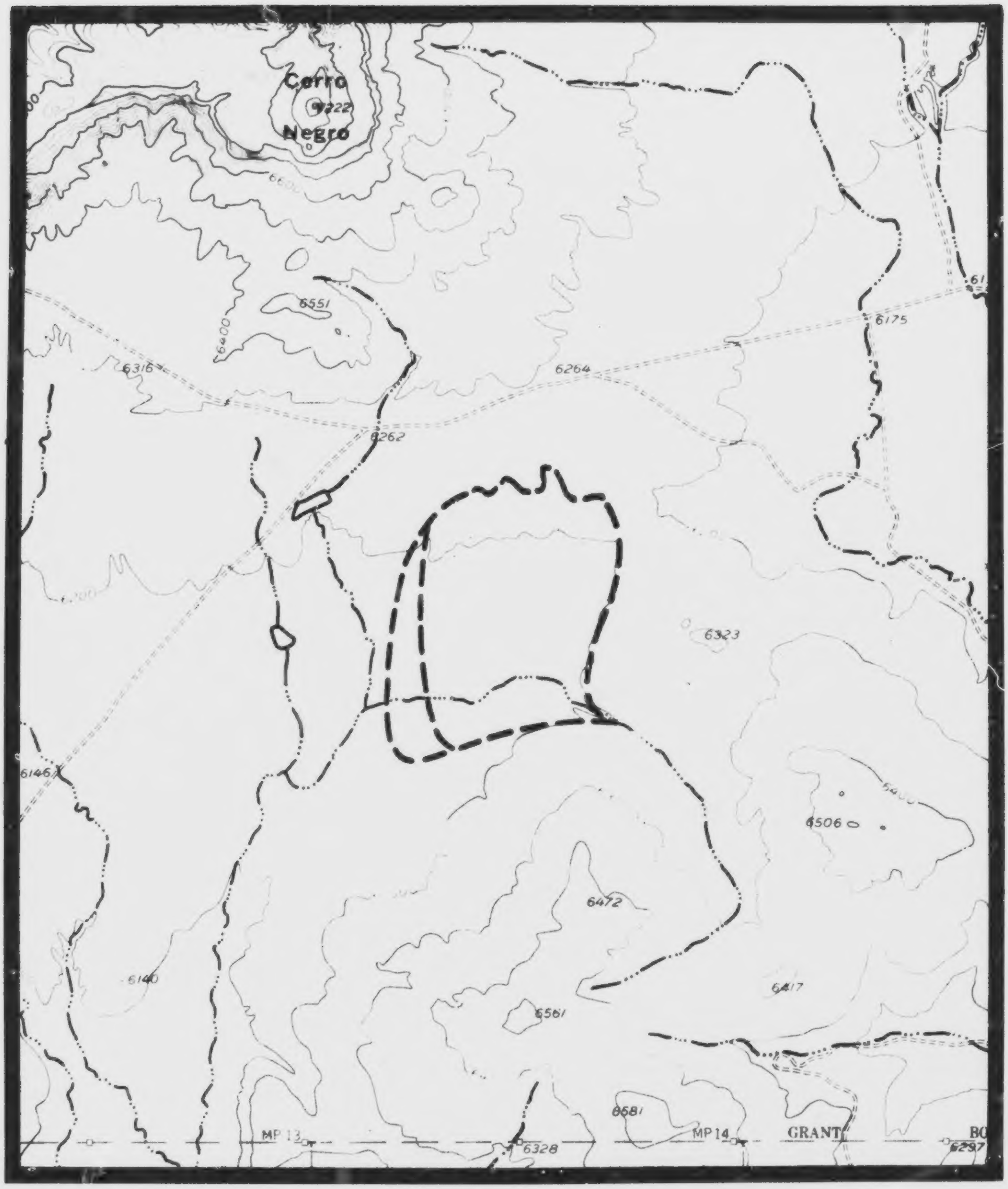
Cerro
Negro
6551
6400
6316
6264
6262
6175
6323
6146
6506
6472
6140
6417
6561
6581
MP 13
6328
MP 14
GRANT
6297

FIGURE A.22. Location of L-Bar (Sohio Petroleum Co.) Mill Tailings (1:24,000) -- Moquino Quadrangle, New Mexico

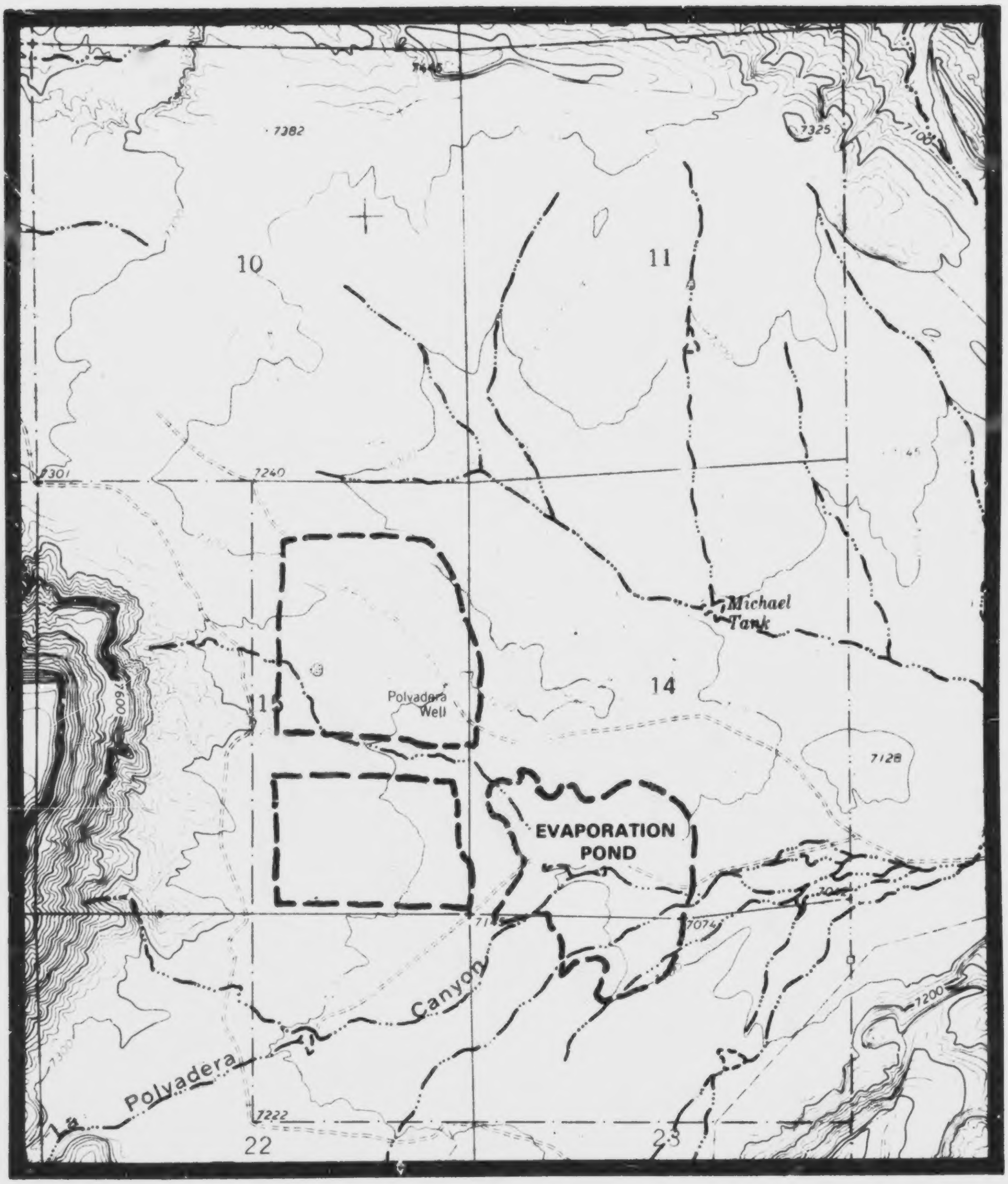
7445
7382
7325
7100
10
11
7301
7240
Michael
Tank
14
15
Polvadera
Well
7128
EVAPORATION
POND
7074
7200
Polvadera
Canyon
7222
22
23

FIGURE A.23. Location of Mt. Taylor Project (Gulf Mineral Resources) Mill Tailings (1:24,000) -- San Lucas Dam, New Mexico

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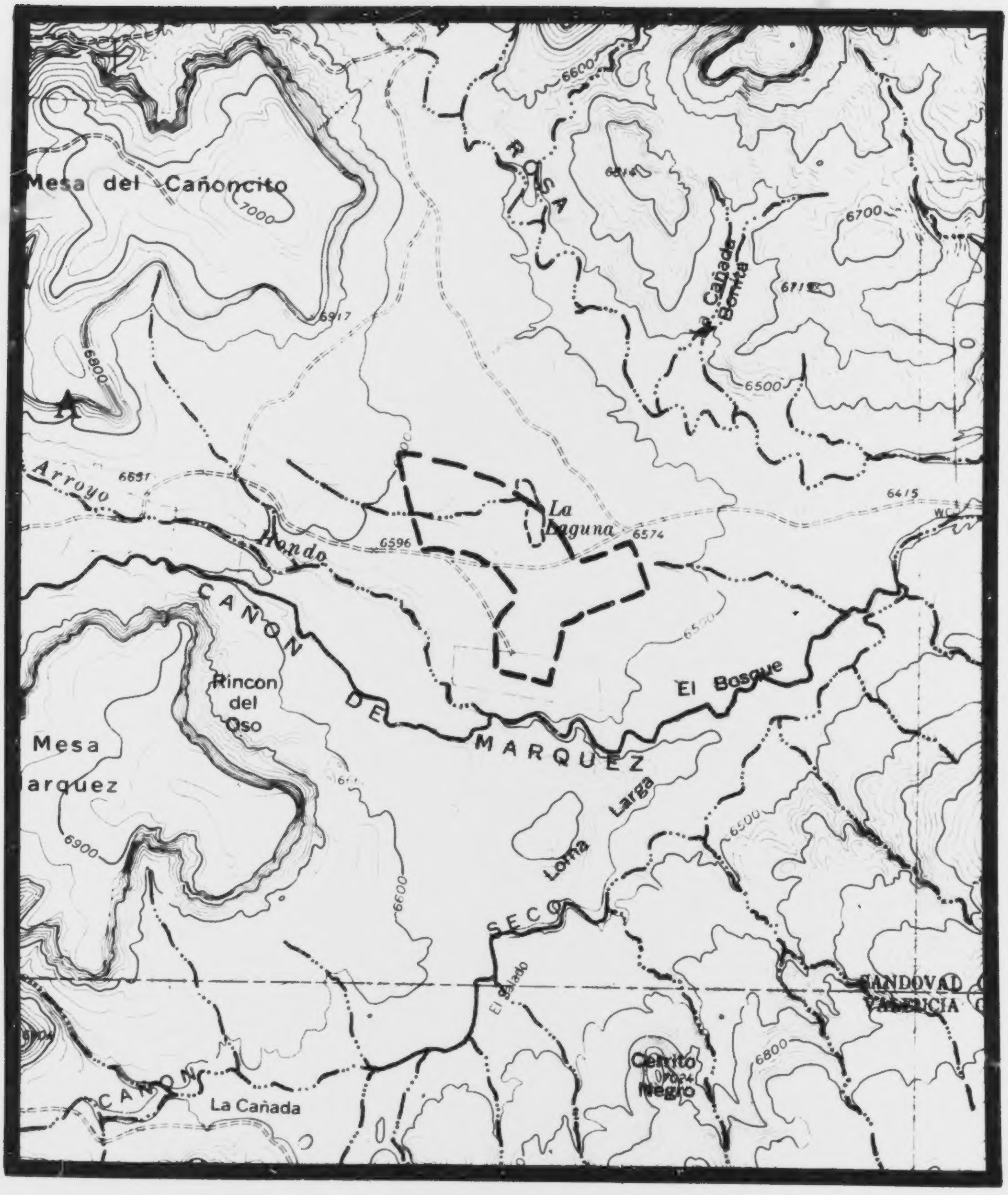
Mesa del Cañoncito
7000
6917
6800
6600
ROSA
6700
La Cañada Bonita
6715
6500
Arroyo
6651
Hondo
6596
La Laguna
6574
6415
CAÑON DE MARQUEZ
Rincon del Oso
Mesa Marquez
6900
El Bosque
Loma Larga
6500
6600
SECO
El Salado
SANDOVAL
VALENCIA
Cerrito Negro
7024
6800
CAÑON
La Cañada

FIGURE A.24. Location of Marquez Project (Bokum Resources) Mill Tailings (1:24,000) -- Marquez Quadrangle, New Mexico

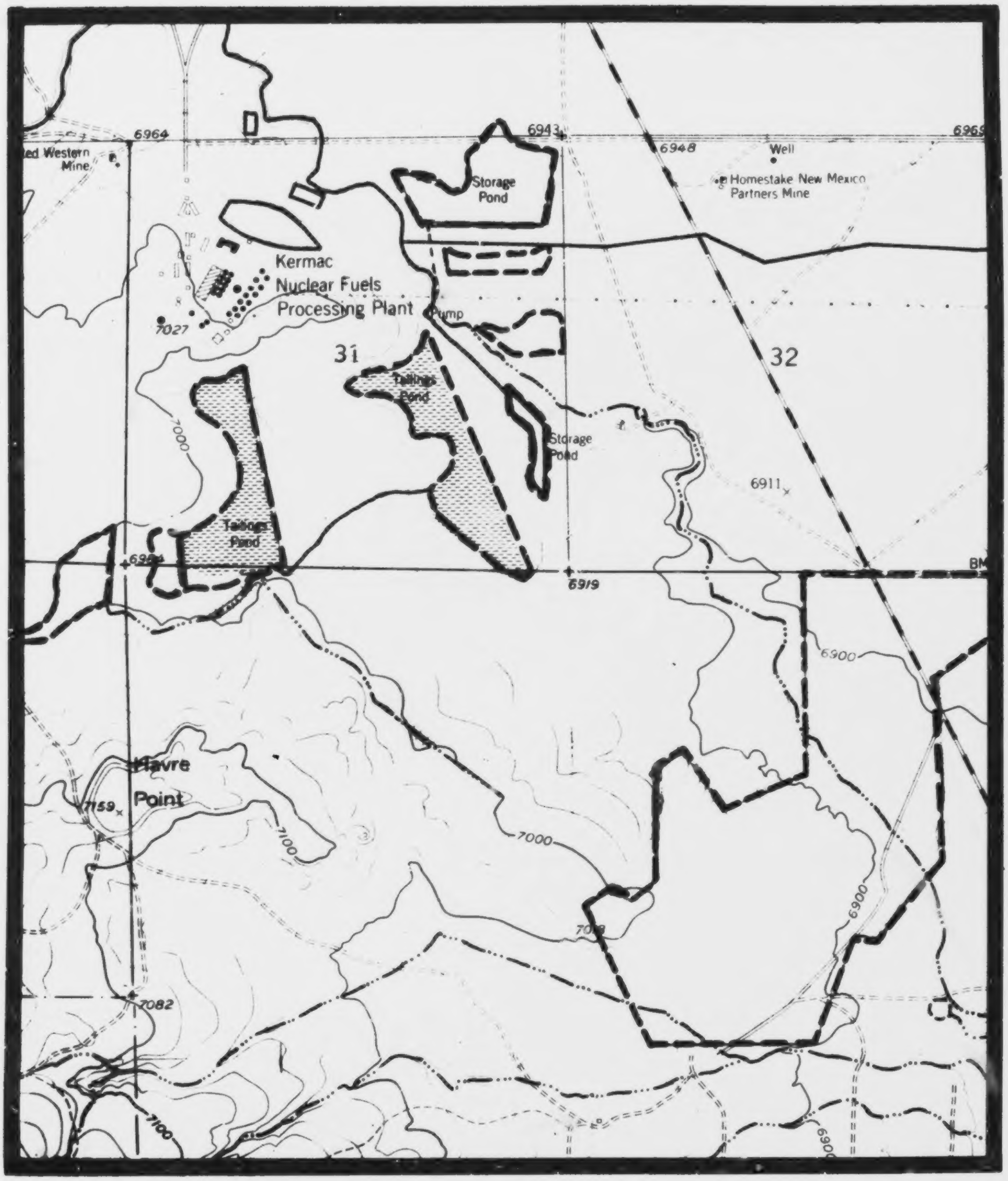
ted Western Mine
6964
6943
6969
6948
Well
Homestake New Mexico Partners Mine
Storage Pond
Kermac Nuclear Fuels Processing Plant
Pump
7027
31
32
Tailings Pond
Storage Pond
7000
6911
Tailings Pond
6964
6919
BM
6900
Havre Point
7159
7100
7000
7000
6900
7082
7100
6900

FIGURE A.25. Location of Ambrosia Lake (Kerr-McGee Nuclear Corp.) Mill Tailings (1:24,000) -- Dos Lomas and Ambrosia Lake Quadrangles, New Mexico

[redacted]

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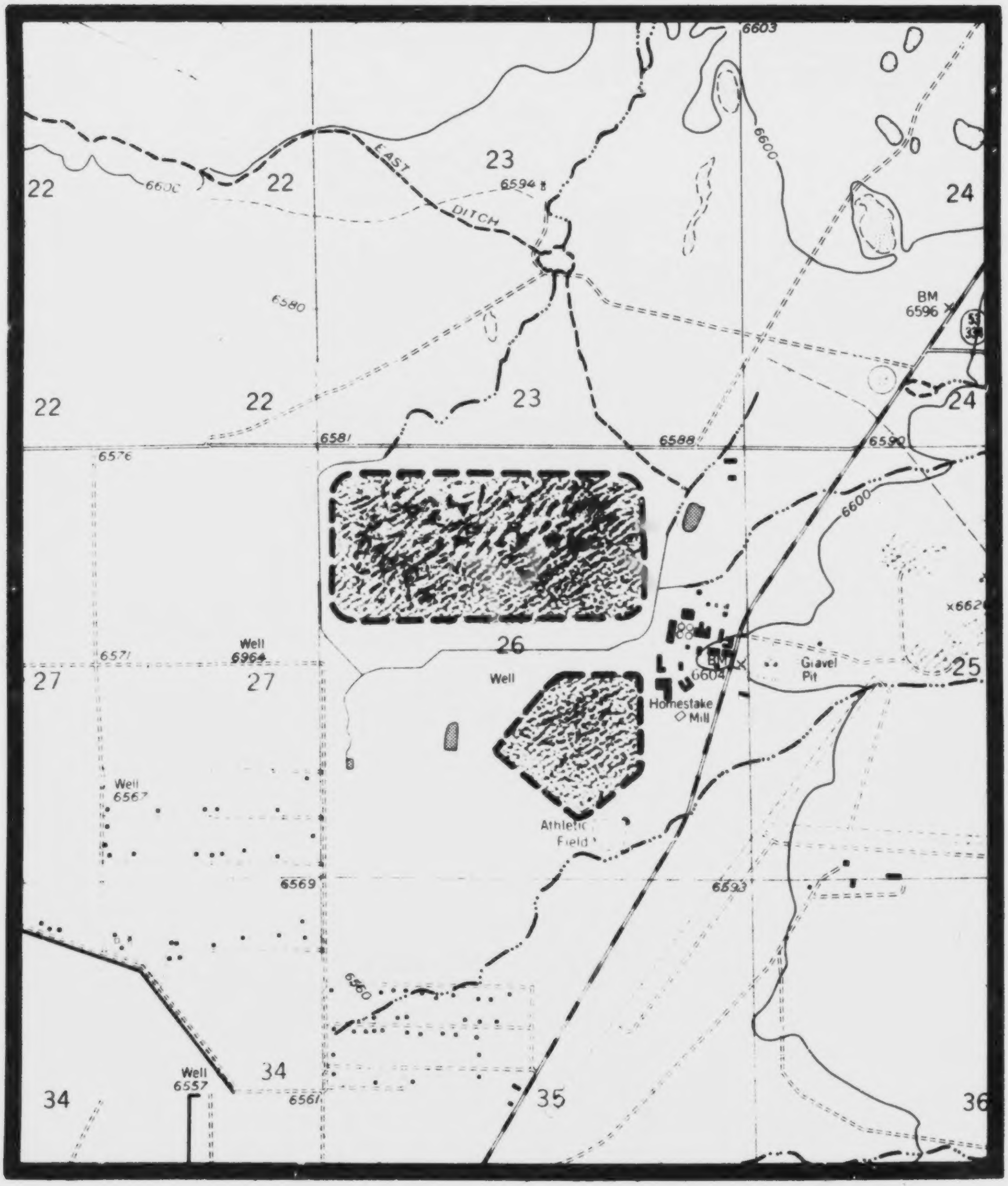
6603
6600
23
22
6600
22
6594
EAST DITCH
24
6580
BM
6596
53
22
22
23
24
6581
6576
6588
6592
6600
x6620
26
Well
6964
6571
27
27
Well
BM
6604
Gravel Pit
25
Homestake
Mill
Well
6567
Athletic
Field
6569
6593
6560
Well
6557
34
34
6561
35
36

FIGURE A.26. Location of Homestake (Homestake Mining Co.) Mill Tailings (1:24,000) -- Dos Lomas, Ambrosia Lake, Bluewater, and Goat Mountain Quadrangles, New Mexico

[redacted]

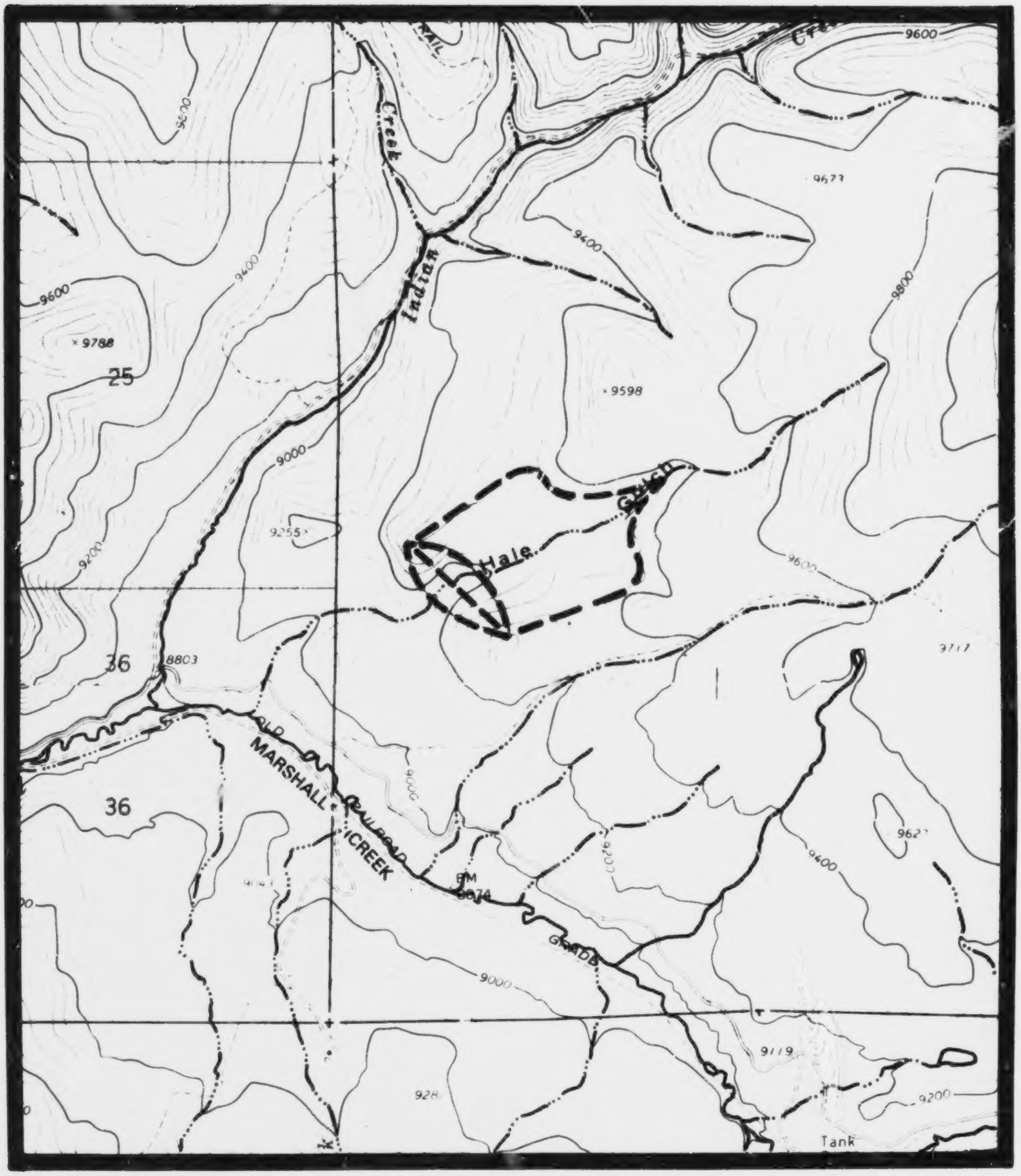
Creek
9600
Creek
Indian
9673
9400
9800
9600
9788
25
9598
9000
Gulch
9255
Hale
9200
9600
9717
36
8803
OLD
MARSHALL
RAILROAD
CREEK
GRADE
36
9000
9400
BM
8874
9000
9119
9200
Tank

FIGURE A.27. Location of Pitch Project (Homestake Mining Co.) Mill Tailings (1:24,000) -- Pahlone Peak Quadrangle, Colorado

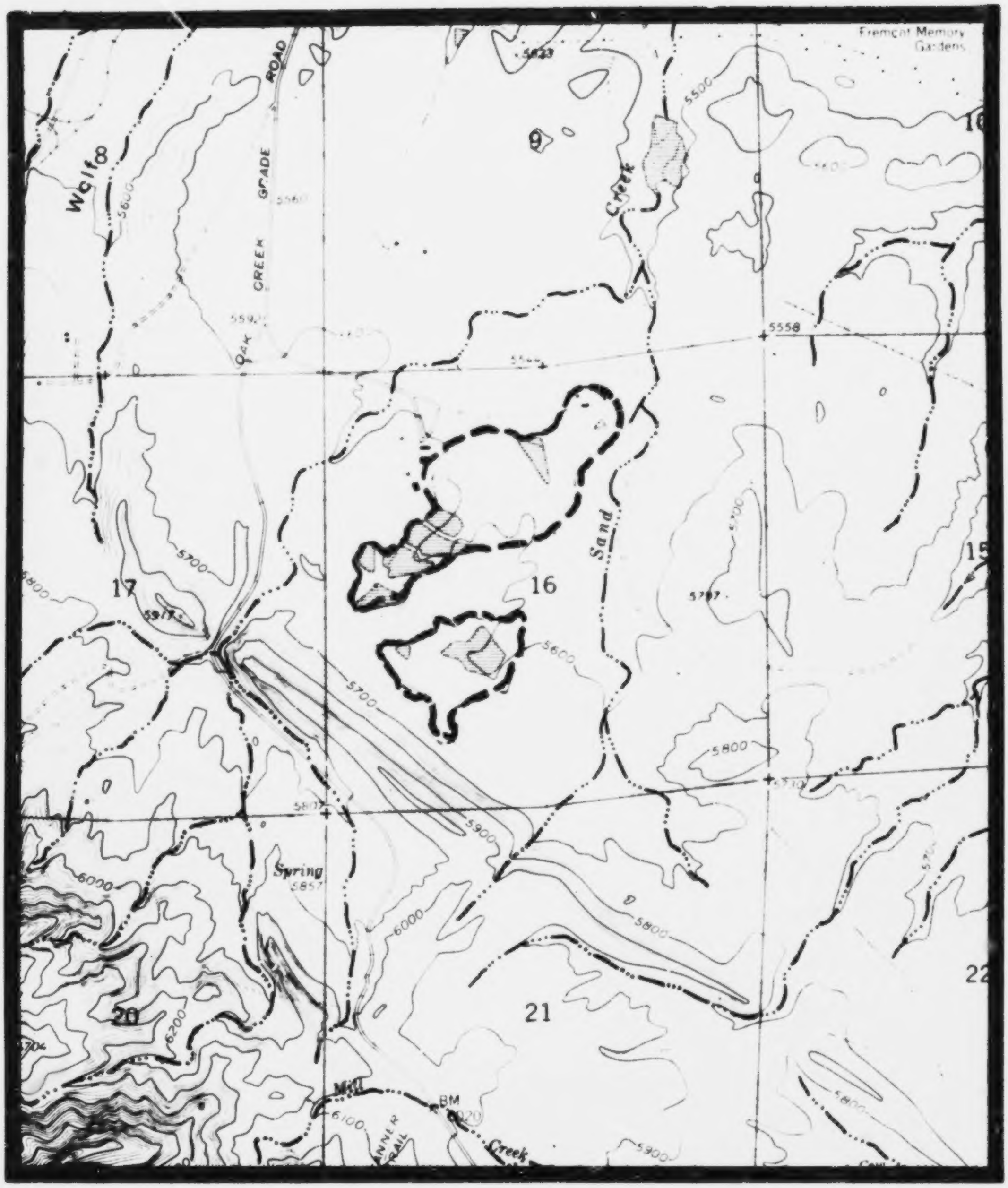
Fremont Memory Gardens
5623
9
Wolf 8
OAK CREEK GRADE ROAD
Creek
5500
5560
5592
5558
5544
16
Sand
17
5700
5800
5917
5600
5797
15
5807
5900
Spring
5857
6000
5800
21
20
6200
22
Mill
BM
5920
6100
Creek
5900

FIGURE A.28. Location of Canon City (Cotter Corp.) Mill Tailings (1:24,000) -- Canon City Quadrangle, Colorado

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Pacific Northwest Laboratory is investigating the use of a rock armoring blanket (riprap) to mitigate wind and water erosion of an earthen radon suppression cover applied to uranium mill tailings. To help determine design stresses for the tailings piles, environmental parameters are characterized for the five active uranium-producing regions on a site-specific basis. Only conventional uranium mills that are currently operating or that are scheduled to open in the mid 1980's are considered.

Available data indicate that flooding has the most potential for disrupting a tailings pile. The arid regions of the Wyoming Basins and the Colorado Plateau are subject to brief storms of high intensity. The Texas Gulf Coast has the highest potential for extreme precipitation from hurricane-related storms. Wind data indicate average wind speeds from 3 to 6 m/sec for the sites, but extremes of 40 m/sec can be expected. Tornado risks range from low to moderate. The Colorado Plateau has the highest seismic potential, with maximum acceleration caused by earthquakes ranging from 0.2 to 0.4 g. Any direct effect from volcanic eruption is negligible, as all mills are located 90 km or more from an igneious or hydrothermal system.

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